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Use of Site Characterization and Analysis Penetrometer System at the Walnut Creek Watershed, Ames, Iowa

by *Landris T. Lee, Jr.*
Geotechnical Laboratory

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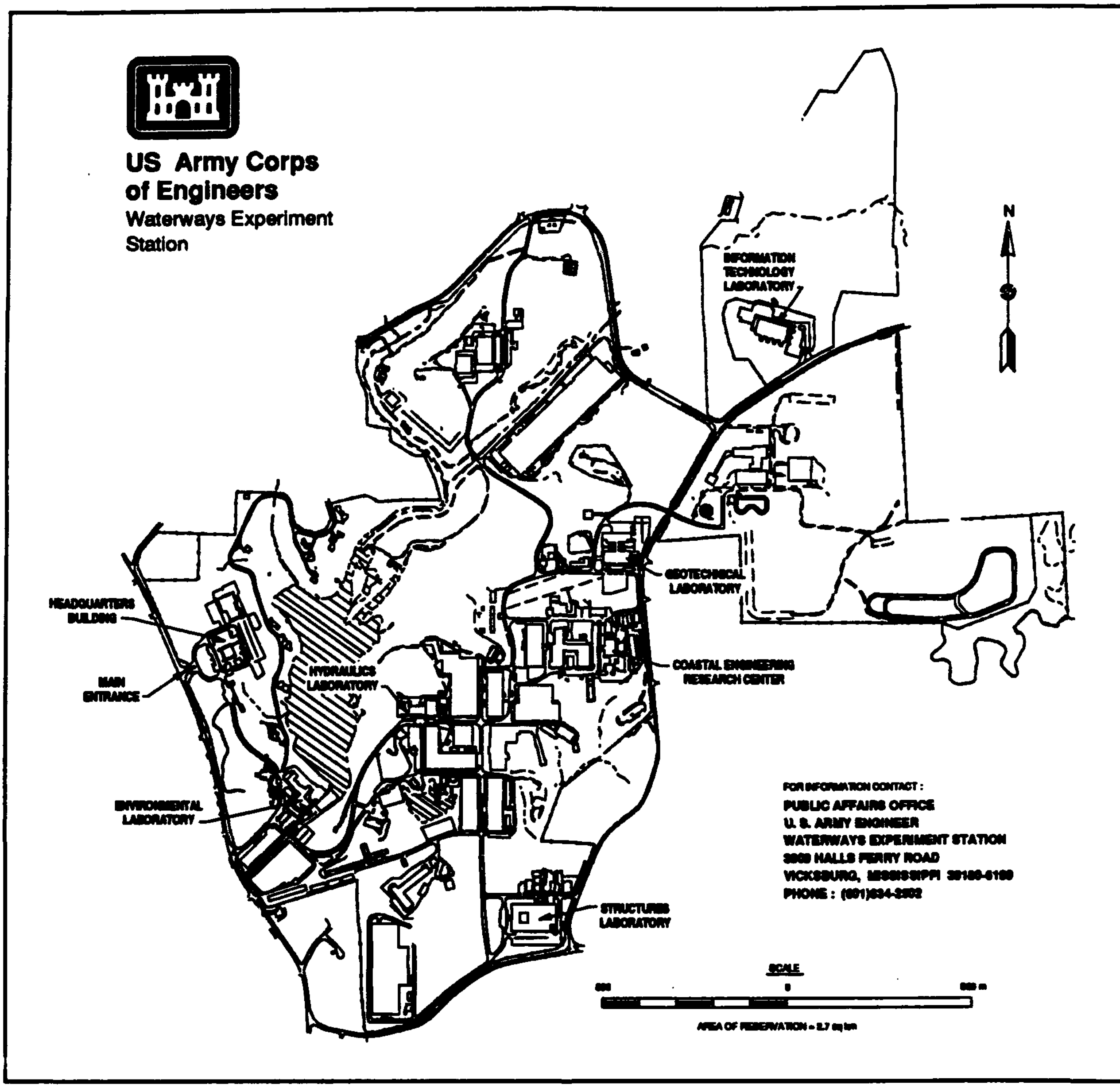
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for U.S. Environmental Protection Agency
Robert S. Kerr Environmental Research Laboratory
Ada, OK 74820



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Preface

The Earthquake Engineering and Geosciences Division (EEGD), Geotechnical Laboratory (GL), Waterways Experiment Station (WES), was tasked by the Environmental Protection Agency (EPA), Robert S. Kerr Environmental Research Laboratory (RSKERL) to conduct subsurface stratigraphy measurements with the Site Characterization and Analysis Penetrometer System (SCAPS).

The nine investigation sites were within the Walnut Creek watershed basin, south of Ames, Iowa, encompassing a total area of approximately 17 square miles. The investigation was conducted from 19 February through 24 February 1993. Coordination was provided by Mr. Stephen R. Kraemer, EPA Project Officer.

The SCAPS field work was conducted by Messrs. Landris T. Lee, Jr. and Donald H. Douglas (Geotechnical Laboratory); Donald S. Harris (Engineering and Construction Services); and Jeff F. Powell (Instrumentation Services Division), WES.

Report preparation was done by Messrs. Landris T. Lee, Jr. and Jeff F. Powell.

The project was under the direct supervision of Mr. Joseph R. Curro, Jr., Chief, Engineering Geophysics Branch; Mr. Mark Vispi, Chief, In Situ Evaluation Branch; Dr. A. G. Franklin, Chief, Earthquake Engineering and Geosciences Division; and Dr. W. F. Marcuson III, Director, Geotechnical Laboratory. The project was under the Environmental Laboratory SCAPS Program management of Dr. John Harrison (Laboratory Director), Dr. Jerome Mahloch (Program Manager), and Mr. John Ballard (Assistant Program Manager).

The Director of WES during the investigation and report preparation was Dr. Robert W. Whalin, and the Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	0.40468	hectares
feet	0.3048	meters
gallons	3.785412	cubic decimeters
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

The U.S. Department of Agriculture's National Soil Tilth Laboratory (NSTL), located on the campus of Iowa State University in Ames, Iowa, is currently committed to a national water quality study focused in the midwestern United States. Within this program, Management System Evaluation Areas (MSEAs) were selected as research sites for study of the complex interactions of soils, weather, water, and farm management systems. One of the sites selected is located in Iowa, within the Walnut Creek watershed area south of Ames, Iowa. This research site extends over approximately 17 square miles (4403 hectares) of privately-owned farmland and Iowa State University properties.

One of the research goals of the MSEA program is to develop modeling components for the transport of water and chemicals through the soil root and vadose zones. The U.S. Environmental Protection Agency Robert S. Kerr Environmental Research Laboratory (EPA/RSKERL) is cooperating with NSTL in studying the subsurface, with particular interest in the groundwater regime. The EPA/RSKERL tasked the U.S. Army Engineer Waterways Experiment Station (WES) to contribute to the research efforts of the Walnut Creek watershed project.

The WES contribution consisted of collecting subsurface soil stratigraphy data utilizing a cone penetrometer at specified locations within the study area (see Figures 1 and 11). The WES Site Characterization and Analysis Penetrometer System (SCAPS) truck was fielded to acquire the data. The SCAPS truck cone penetrometer was pushed to various depths on the specified farmland sites within the watershed, and the soil stratigraphy at those locations was determined from the resulting penetrometer data. The cone penetrometer data were augmented by soil core data collected by other government agencies.

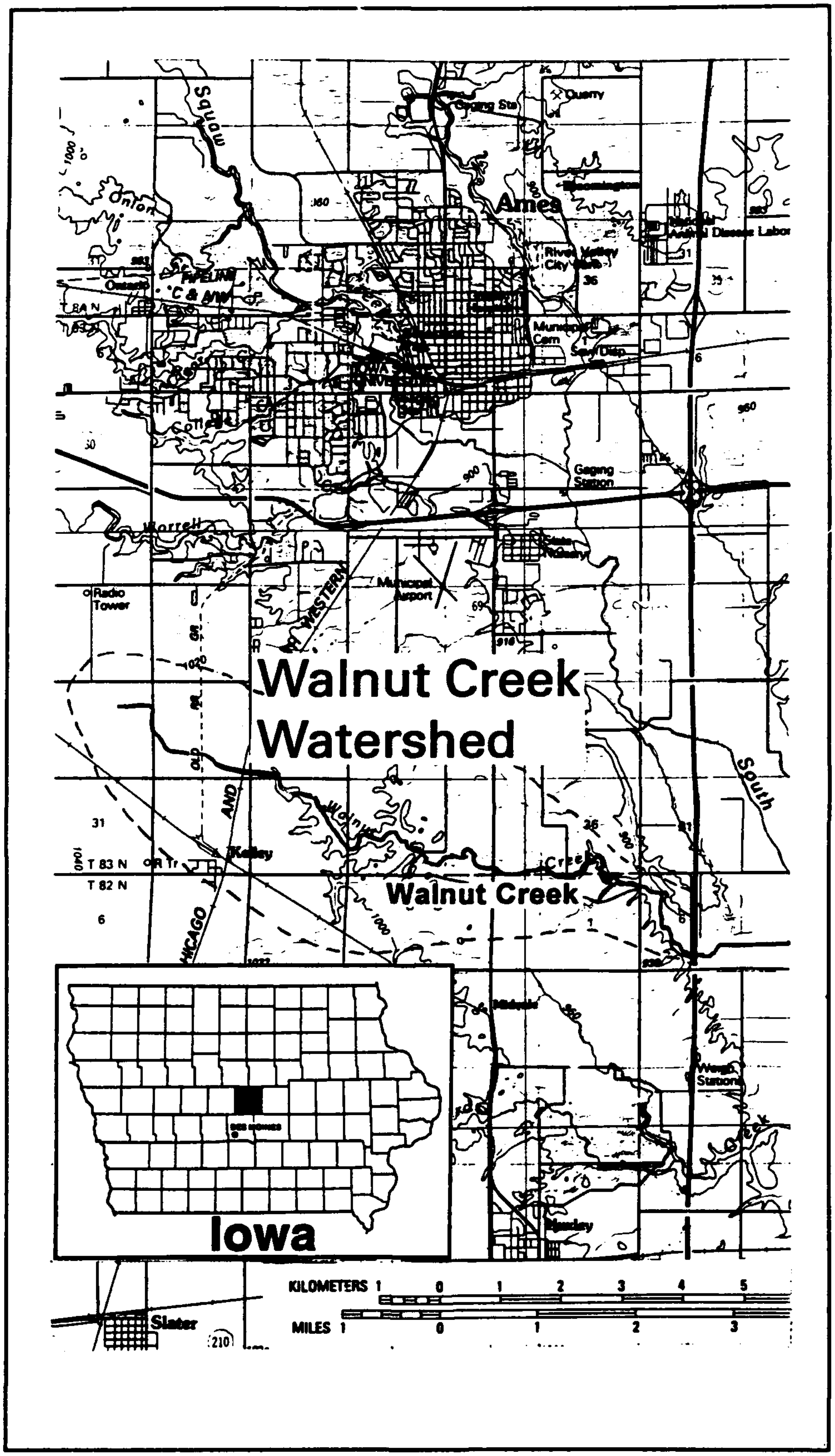


Figure 1. Site locator map

2 Site Description

General

The Walnut Creek watershed encompasses approximately 17 square miles (4403 hectares) within Boone and Story counties of central Iowa (Figure 1). Walnut Creek traverses rolling hills along the route from its upper reaches near the community of Kelley flowing southeastward to its confluence with the South Skunk River below the city of Ames. The land surface topography varies from about 1050 ft (318 meters) above mean sea level in the northwest area of the watershed to about 860 ft (261 meters) above mean sea level in the southeast area. The majority of the watershed land surface is farmland; wooded areas are prominent adjacent to Walnut Creek.

Soils and Geology

The surface terrain varies from gently rolling hills in the upper reaches of the watershed to a wide, flat alluvial plain near the confluence of Walnut Creek and South Skunk River. The transition zones between upland and alluvium are well defined topographically. The surface soils are poorly drained as a general rule; the upper reaches of the watershed are often covered by water - filled potholes at the beginning of the spring planting season, and are underlain by a pattern of tile drains for faster drainage. Surface runoff drainage predominates in the lower reaches of the watershed (in the alluvial plain).

The surface soils consist of the Clarion-Nicollet-Webster (CNW) series in the uplands and the Copland-Spillville-Zook (CSZ) series in the alluvial bottomlands. The Clarion-Storden-Coland (CSC) series is present in transition areas adjacent to the steeply cut creek banks (DeWitt 1984). The CNW series consists of black loamy soils formed in glacial till, and is characterized by an undulating ground moraine of swales and rises that differ from about 5 to 10 ft in elevation. Surface drainage is poorly developed, and runoff water periodically accumulates in scattered depressions. The natural fertility level of the soils is high and corn crop productivity is among the nation's highest. The CSZ association consists of nearly level, moderately well drained to poorly drained, loamy and silty soils formed in alluvium. The CSC

association is characterized by dissected glacial moraine areas, and consists of loamy soils formed in glacial till or alluvium.

The site consists of glacial till and loess deposits of the Pleistocene Epoch (Quaternary Period), underlain by limestone bedrock of the Mississippian Period. Figures 2 and 3 indicate the general geologic stratification taken from domestic water well logs within the watershed. No water levels in the wells are indicated. Current research efforts are devoted to obtaining more accurate geological details within the watershed.

Pleistocene glacial deposits in the midwestern United States have been regarded as one of the most complex and variable of all geologic materials. Iowa's Pleistocene record contains both glacial and interglacial deposits; the sequence of glacial ages covering the study site arranged chronologically include the Wisconsinan Glacial, Sangamon Interglacial, and Illinoisan Glacial. Iowa emerged from the Late Wisconsin (Cary) glaciation about 13,000 years ago. The Bemis Moraine (Des Moines Lobe) was formed along the margins of the Cary glacier as it retreated across the future Walnut Creek watershed site in central Iowa. The deposits left by the advancing and retreating glaciers include glacial drift (material carried by the glacier), glacial till (material deposited by glacial ice), glaciofluvial (deposited by meltwaters), and loess (wind-carried fine rock powder produced from the grinding effects of glaciers). Interglacial deposition was not prevalent; weathering and erosion were the dominant processes. Such weathering and erosion processes are evidenced by old soil horizons, weathered zones, alluvial deposits, and lacustrine deposits (Anderson, 1983).

Glacial deposition occurs subglacially (at the glacier base and often referred to as "basal)" and supraglacially (on the upper surface of the ice). Geotechnical properties and behavior of the deposited materials are functions of each of these depositional environments. Texture, density, and structure are three fundamental properties which determine the geotechnical behavior of most glacial deposits; these properties are acquired from the depositional environment, whether it be basal or supraglacial. Basal till is generally characterized by uniform textural and mineralogical properties. It also tends to contain few interbedded lenses of meltwater silts, sands, or gravels. Any such variation to these generalities usually occurs at the base of the till unit. Supraglacial deposits tend to be much more complex; these deposits are poorly sorted till-like materials and are generically referred to as "diamicton." Diamictions exhibit larger variations in texture, recognizably lower densities, and more stratified structures than those present in basal till materials (Lutenegger. et al 1983).

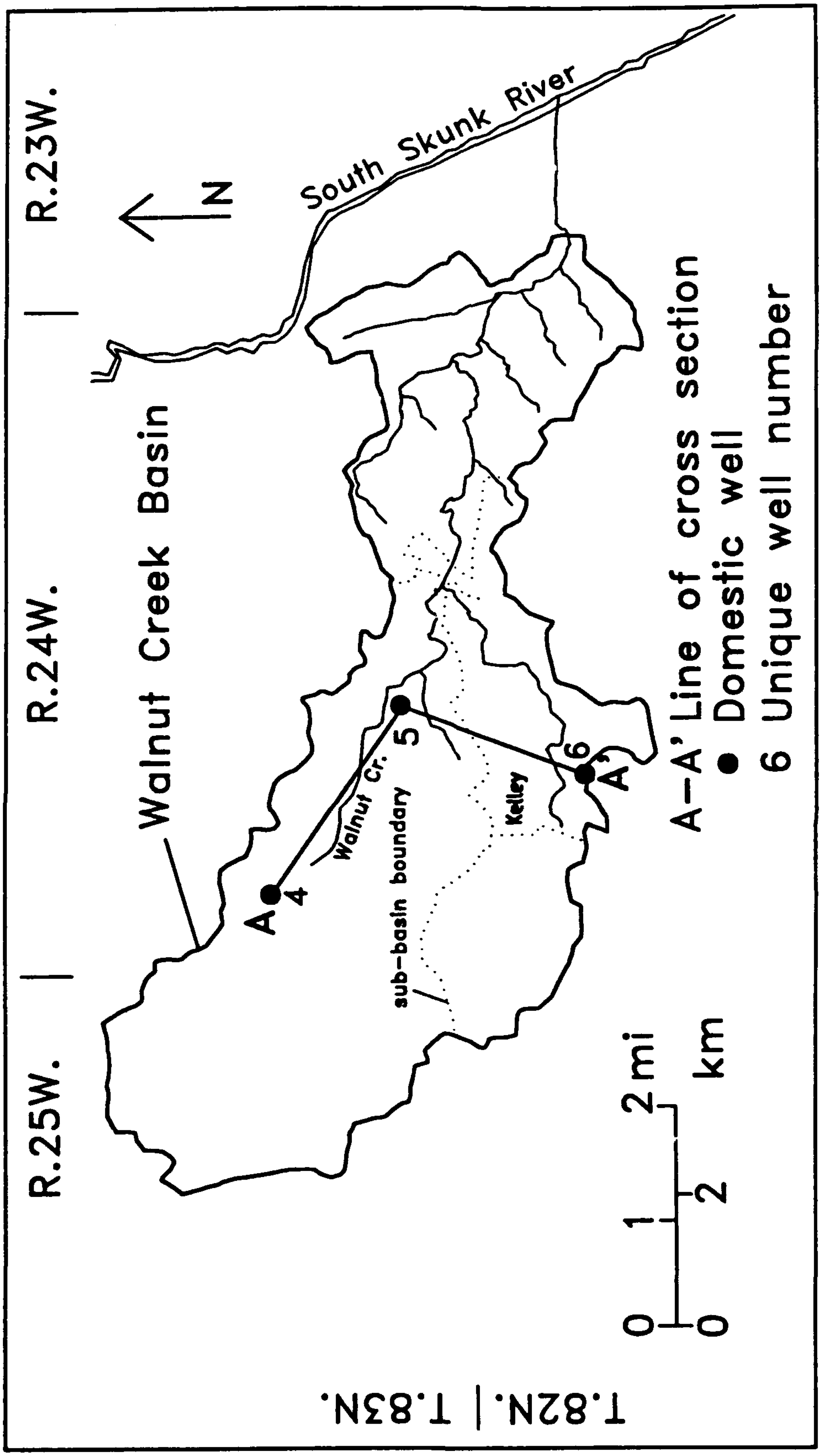


Figure 2. Walnut creek watershed basin map

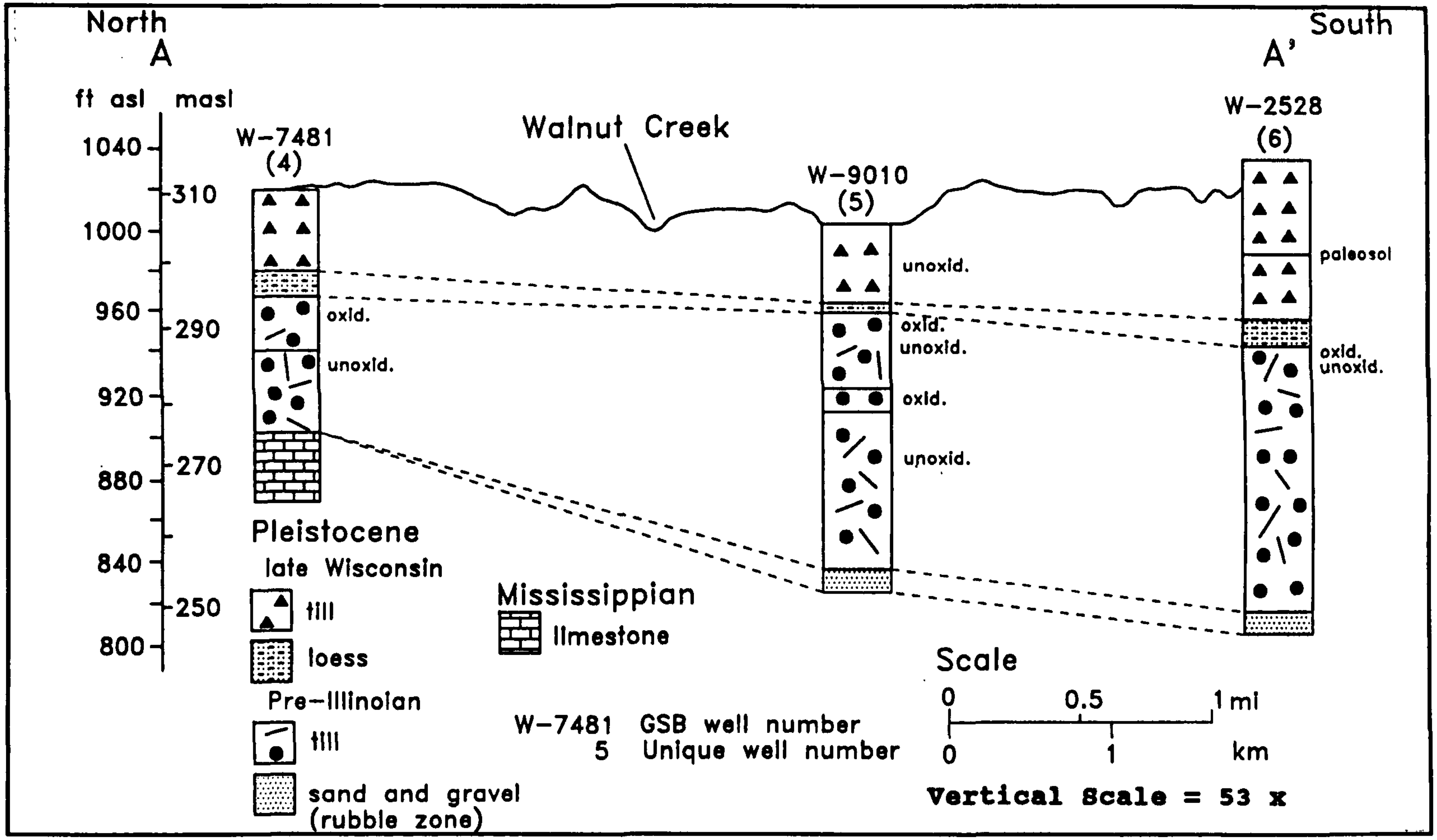


Figure 3. Section A-A Figure 2 through the watershed basin showing generalized geological patterns (from Simpkins, 1993)

3 Equipment and Procedures

General

The Site Characterization and Analysis Penetrometer System (SCAPS), is an integrated ensemble of surface geophysical equipment, survey and mapping equipment, cone penetrometers with sensors for soil classification and contaminant detection, and soil and pore fluid penetrometer samplers. The experimental penetrometer system is mounted in a specially-engineered truck (Figure 4) designed with protected work spaces to allow access to toxic and hazardous sites while minimizing exposure of the work crew. Since the Walnut Creek watershed project did not involve hazardous or toxic wastes, any references to contaminated sites hereinafter are intended only in reference to the SCAPS capability to operate in such environments.

The major component of the SCAPS system is a 20-ton (18,143 kg), all-wheel-drive penetrometer truck that was designed specifically for operations at hazardous waste sites. The truck carries a hydraulic power unit and controls to operate the push apparatus, a power takeoff driven 25-kw generator, dual air conditioning units, separated push and data acquisition work spaces, a shock-isolated floor for the penetrometer instrumentation, easily decontaminated stainless steel van body, and other personnel protection features. A specially designed trailer is used to carry the grouting pump, water tank, and a closed-loop steam cleaner to clean the penetrometer rods and tools as they are withdrawn from the soil.

The SCAPS penetrometers are equipped with sensors including those that can determine physical and fluorescence characteristics of the soil as the penetrometer tip is forced through the soil, creating a 1.4 in (3.5 cm) diameter hole. Sensors include strain gauges for measuring cone tip and sidewall friction forces, an electrical direct current resistivity module and the laser-induced fluorometry module. Figure 5 shows the basic configuration of the SCAPS truck without the resistivity or fluorometry sensors.

All sensors acquire data in real time (concurrent with the penetrometer travel through the soil), and a computer-based data collection and analysis system permits a display and partial interpretation of data in the instrument compartment on the penetrometer truck. The data analysis system also allows processing of various types of surface geophysical and mapping data collected on site, and integration of data into a unified data base. Fluid and soil samples

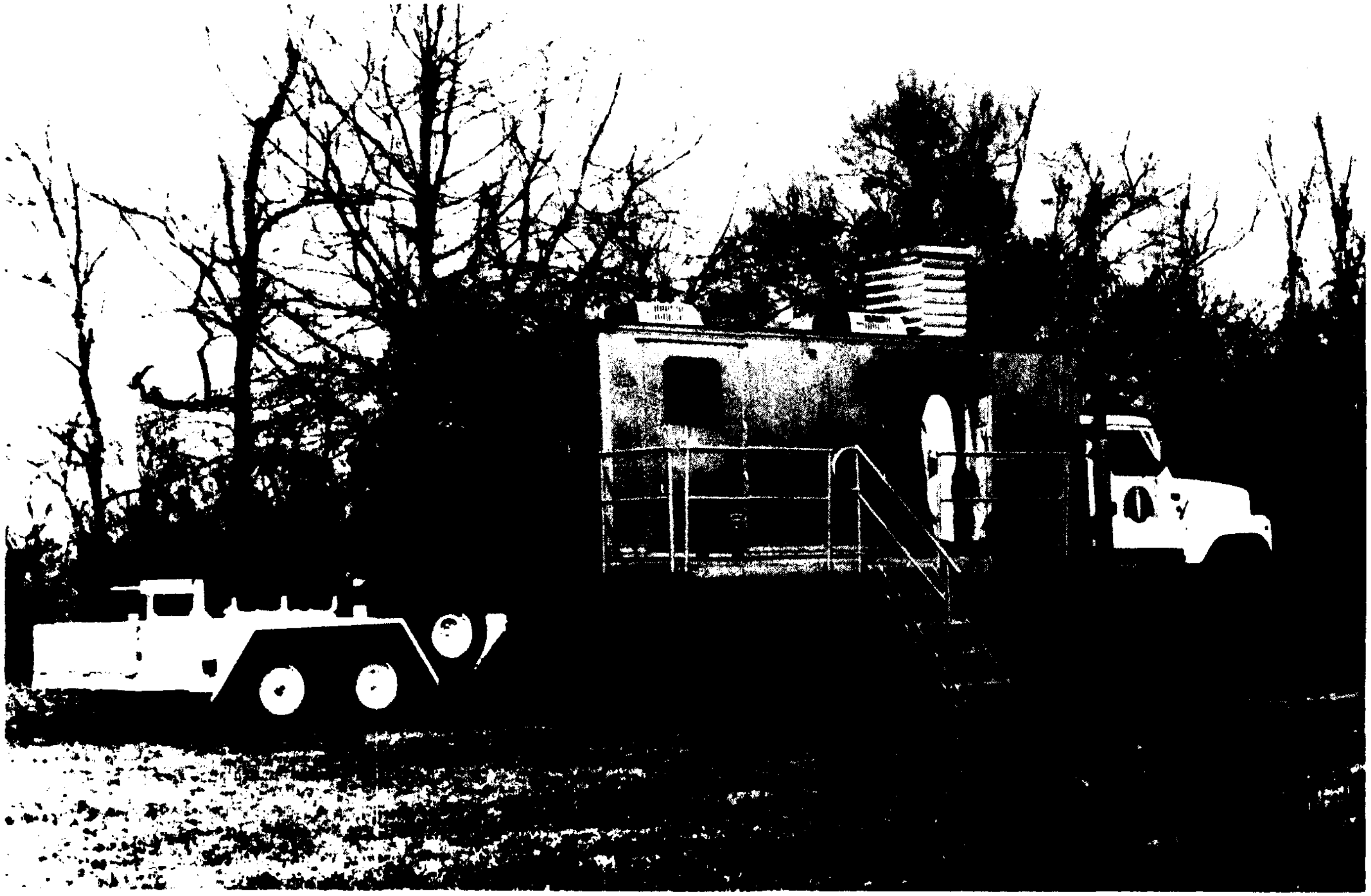


Figure 4. The SCAPS truck

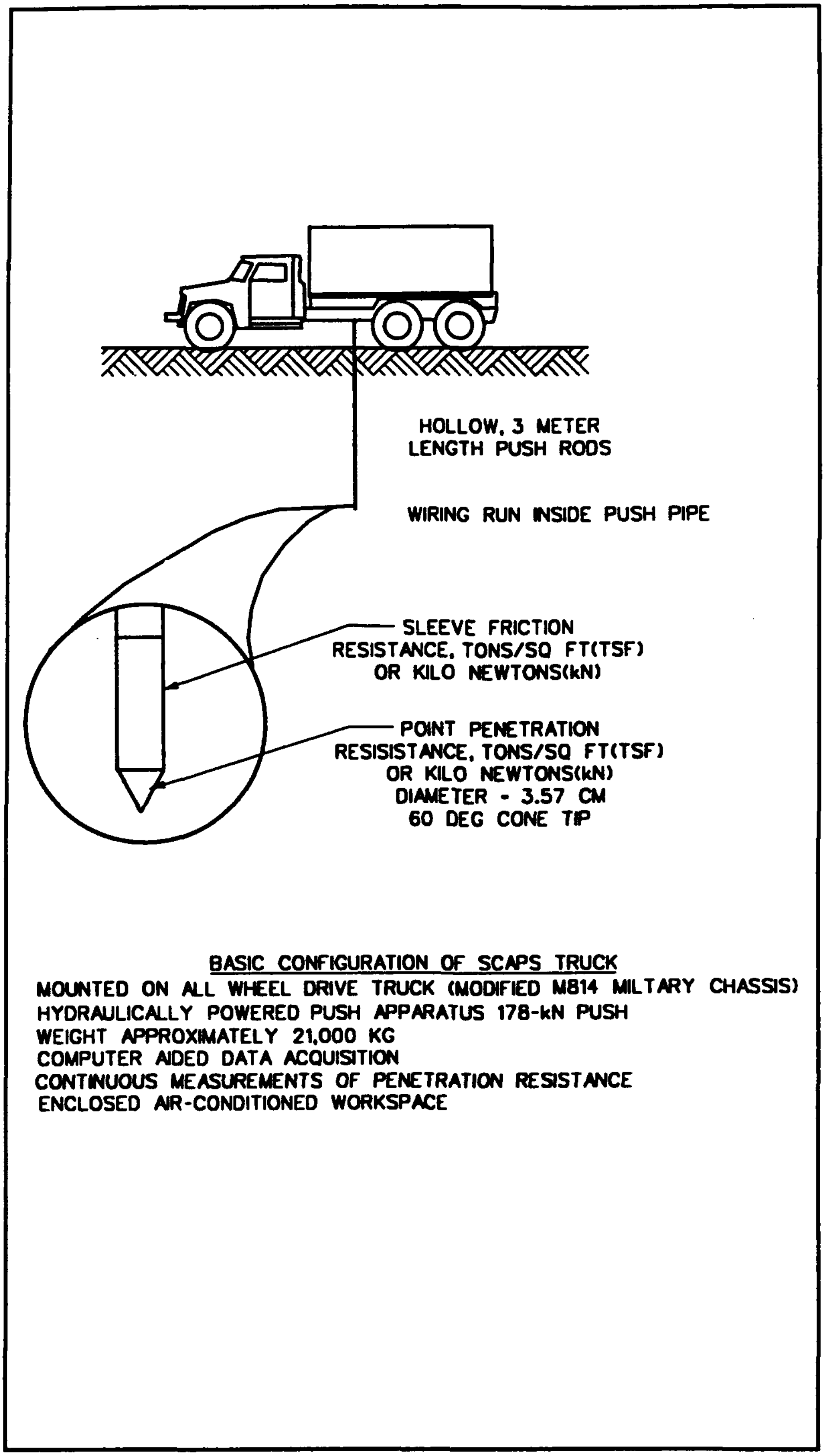


Figure 5. The basic configuration of the SCAPS truck

can be collected using groundwater and soil samplers that are designed for use with penetrometers. The SCAPS system is also equipped to seal each penetrometer hole with grout as the probe is retracted. Details of the above capabilities are described in the following sections of this report.

Site Mapping

The location of penetrometer push points is normally accomplished using a total station electronic distance measuring (EDM) system, consisting of a theolodite and data logger. The location and elevations of penetrometer push points are then overlain onto a local site map for reference. The Global Positioning System (GPS) was utilized at the Walnut Creek project site in lieu of the EDM method. The GPS data acquisition and processing was performed by the USDA National Soil Tilth Laboratory. The processed data (in Iowa State Plane coordinates) was then furnished to the WES SCAPS. The GPS coordinate resolution and accuracy is dependent on the surveying methods utilized by the data collection team at each site. The elevations (in feet above mean sea level) were interpolated from topographic map contours, and are accurate to within 10 ft. The topographic maps utilized were the Slater and Huxley, Iowa, USGS 7.5 min Series.

Geophysical Investigations

Geophysical site surveys are undertaken primarily to determine if there is metallic debris or underground utilities in the area where the penetrometer unit will be operating. The geophysical techniques available for use in conjunction with the SCAPS truck are ground penetrating radar, magnetometry, and electromagnetic induction. No geophysical investigations were conducted at the Walnut Creek project site, since no buried obstacles and underground utilities were anticipated or encountered.

Sampling Methods

No soil or groundwater sampling was performed during the Walnut Creek project; however, the SCAPS system is capable of obtaining both soil and fluid samples utilizing commercial samplers available for use with cone penetrometer equipment. These samplers attach to any standard cone penetrometer and are frequently used for sample collection. The soil sampler is a common "grab sampler" that is controlled from the surface to obtain a specimen at whatever elevation is required. The fluid sampler consists of placing the device at a particular elevation and exposing the screened catch basin to the in-situ environment and waiting a length of time to insure insurgence of fluids into the device.

Grouting Methods

The SCAPS unit is equipped to seal the penetrometer holes as the rod is withdrawn, using a conventional cement/bentonite grout mixer and a low-pressure progressive cavity pump. The mineral grout is pumped through a central tube in the push rod cable and exits through the probe tip. Retraction grouting (as the rod is withdrawn through the soil) with a microfine Portland cement grout is normally utilized for all projects; however, subfreezing weather mandated that post - retraction grouting be accomplished at the Walnut Creek project.

Soil Strength and Type Determination Methods

A sectional view of a penetrometer equipped to measure soil strength is shown in Figure 6. The electrical resistivity sensor module is also shown. The point load cell is loaded in compression as the cone tip is advanced. The friction sleeve load cell is in the form of a hollow cylinder which is split along its cylindrical axis and strain gauged on the inside surface of each half shell. The cell surrounds the tip load cell and is also loaded in compression when soil friction acts on the friction sleeve which jackets the front of the probe. The design employed in this soil strength unit allows the tip penetration resistance and sleeve friction to be made independently and continuously.

Calibration procedures enable creation of separate calibration curves for the strain-gauged cone tip penetration resistance and sleeve friction. The calibration procedures are accomplished once at the beginning of each site investigation, and thereafter as required should the output voltages vary from the initial calibration values. The point resistance load cell is calibrated by cycling the load from zero load to approximately 7272 Kgf and back to zero load several times. A hydraulic line operated by a manually operated hand pump (Porta-Power™) is attached to the load cell. The cell is then loaded to selected load increments and back to zero. The load cell output voltage is read for each load increment applied and the zero load condition at the beginning and end of each loading increment. The load increments are increased until the compressive force reaches the maximum capacity of the cell. The friction sleeve load cell is calibrated in a similar fashion; the friction sleeve is positioned on the load cell to allow independent friction sleeve load voltages to be measured. Figure 7 shows the calibration curves obtained for the load cells used on the Walnut Creek project. Each load cell is calibrated independently but the output of each cell is measured as the calibration proceeds so that any influence of one cell on the output of the other can be determined. Typically neither cell shows any influence on the other. Calibration test responses are generally within 0.5 percent of the applied load.

Techniques for using the soil strength measurements (cone tip and sleeve friction) made with the cone penetrometer to determine soil type have been well-documented (Campanella and Robertson, 1982; Olsen and Farr, 1986; Olsen, 1988). The specification for the penetrometer equipment and the

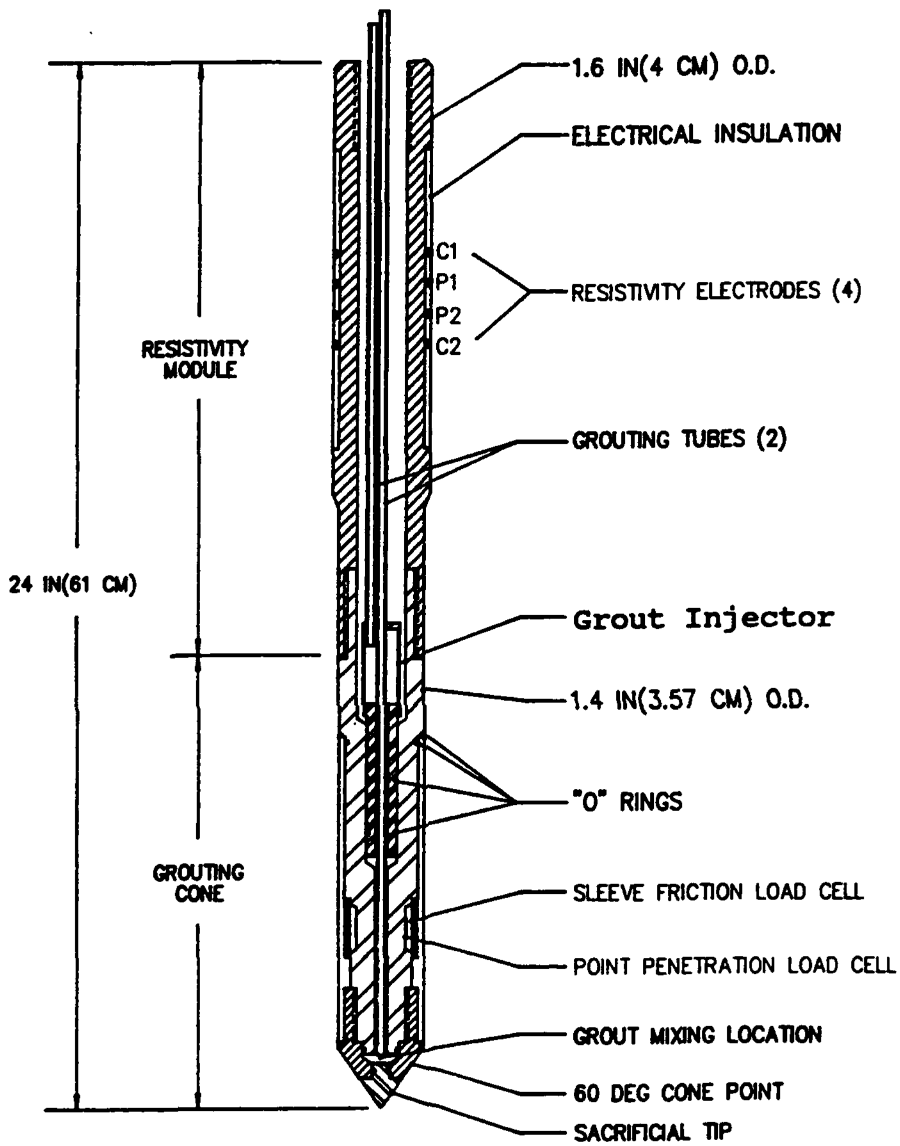


Figure 6. Cone penetrometer cross section, with the electrical resistivity sensor attached

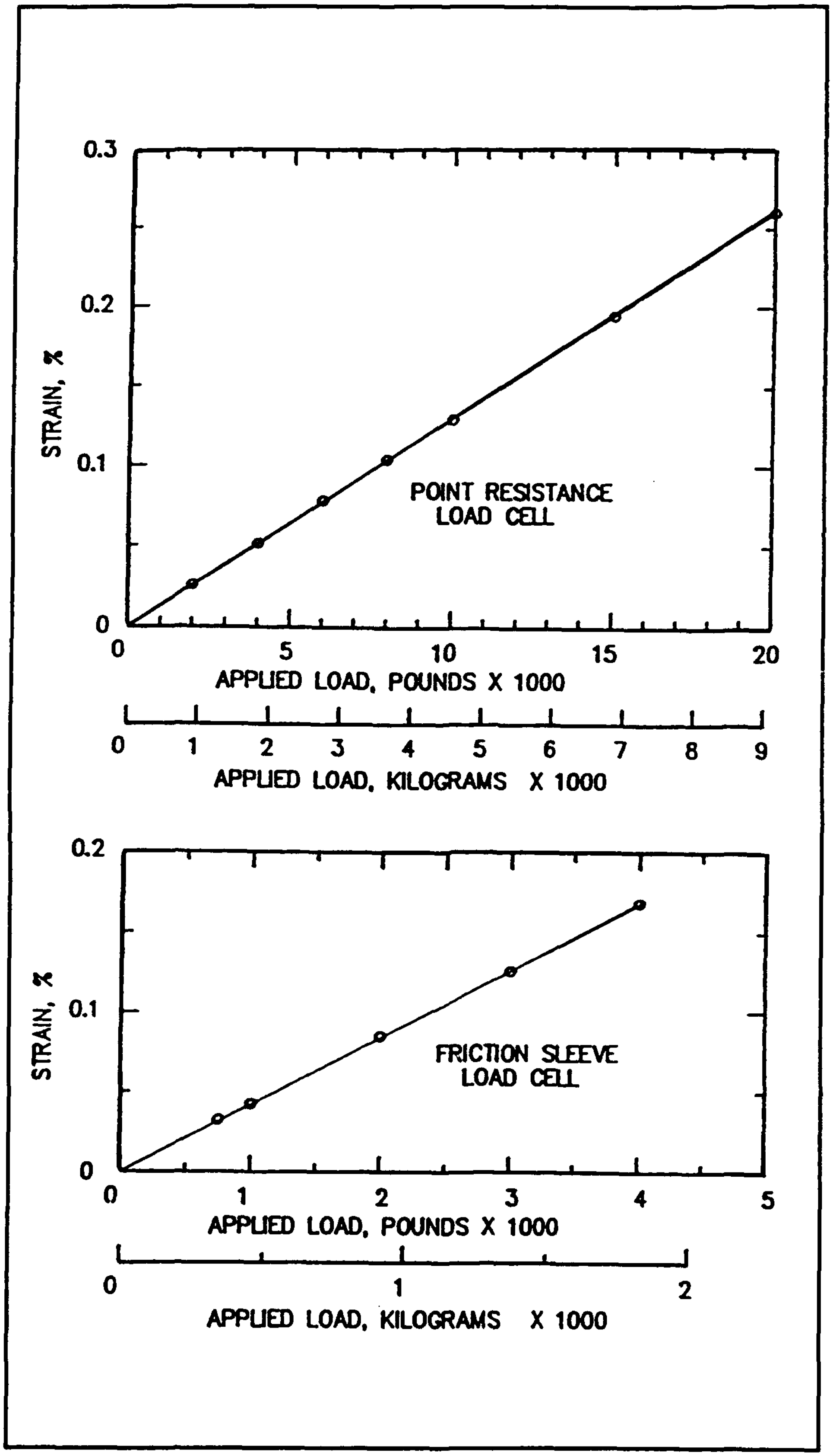


Figure 7. Calibration curves for soil classification

method of gathering data are given by ASTM (1991). Curves relating the soil type and strength measurements made with the cone penetrometer have been published for a large variety of equipment (U.S. Department of Transportation, 1978; Douglas and Olsen, 1981). The classification scheme used by the SCAPS system was devised by Olsen (1988) to identify the types of soils encountered by the CPT probe. The chart used in the cone penetrometer test (CPT) soil classification scheme is shown in Figure 8. Basic soil types can be identified by the combinations of corrected values of sleeve friction and cone resistance, f_{sn} and q_{cn}. The corrected parameters, f_{sn} and q_{cn}, are the results of adjustments made to the measured values of sleeve friction and cone resistance, f_s and q_c. These adjustments correct the measured values to overburden stress conditions of 1 ton/ft^2. In the computer algorithm for mapping the CPT parameters onto the soil classification chart, the output is a Soil Characterization Number (SCN) which correlates to basic soil types. A CPT SCN of 0.5 is a typical clay, the range of SCN's of 1 to 2 represents silt mixtures, SCN's for sands range from 2 to 4, and a fine sand has a SCN between 2.5 and 3.5. The SCN chart is automatically output in the data set displayed immediately after each penetrometer push. Figure 9 indicates the graphical representation comparing the SCN and the Unified Soil Classification System (USCS).

Soil Resistivity Measurement Method

Penetrometer soil direct current (DC) electrical resistivity measurements were performed at the initial site using equipment similar to that described in Cooper et al. (1988). A cross section showing the construction of the penetrometer DC resistivity module is shown in Figure 6. The resistivity unit contains four stainless steel electrodes equally spaced in a Wenner array on an electrically insulated section of penetrometer rod. The outer surface of each electrode is flush with the surface of the insulation material, which consists of machined Teflon™ cylindrical sleeves. The resistivity module is slightly larger in diameter than the standard penetrometer rod (4.06 cm compared to 3.56 cm) to assure that the electrodes make uniform contact with the surrounding soil.

Resistivity measurements are made by passing a bipolar DC current between the two outer electrodes and measuring the voltage drop across the two inner electrodes. The power supply for the resistivity unit is designed to maintain a small constant current (20 milliamperes) through the excitation circuit. The apparent resistivity is calculated using the excitation current, the voltage drop across the inner electrodes, and predetermined geometric factors derived from potential field theory.

Penetrometer resistivity modules are calibrated using the SCAPS truck data acquisition system and software in the same manner as for field data acquisition. The resistivity module is calibrated by immersing the electrode array in a vertical plastic cylinder (25 cm in diameter) filled with distilled water so that the measurement electrodes are at least 12 cm below the water surface.

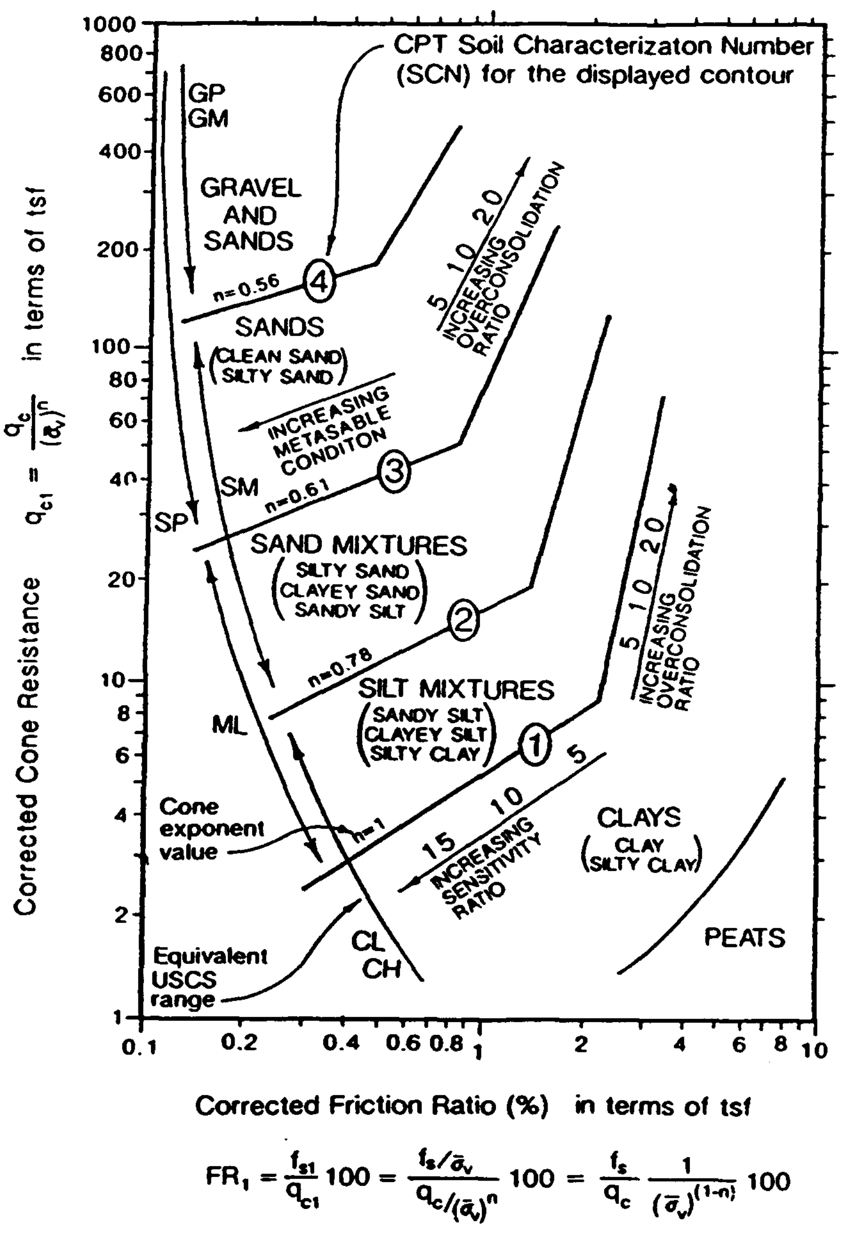


Figure 8. Soil classification curves (from Olsen, 1988)

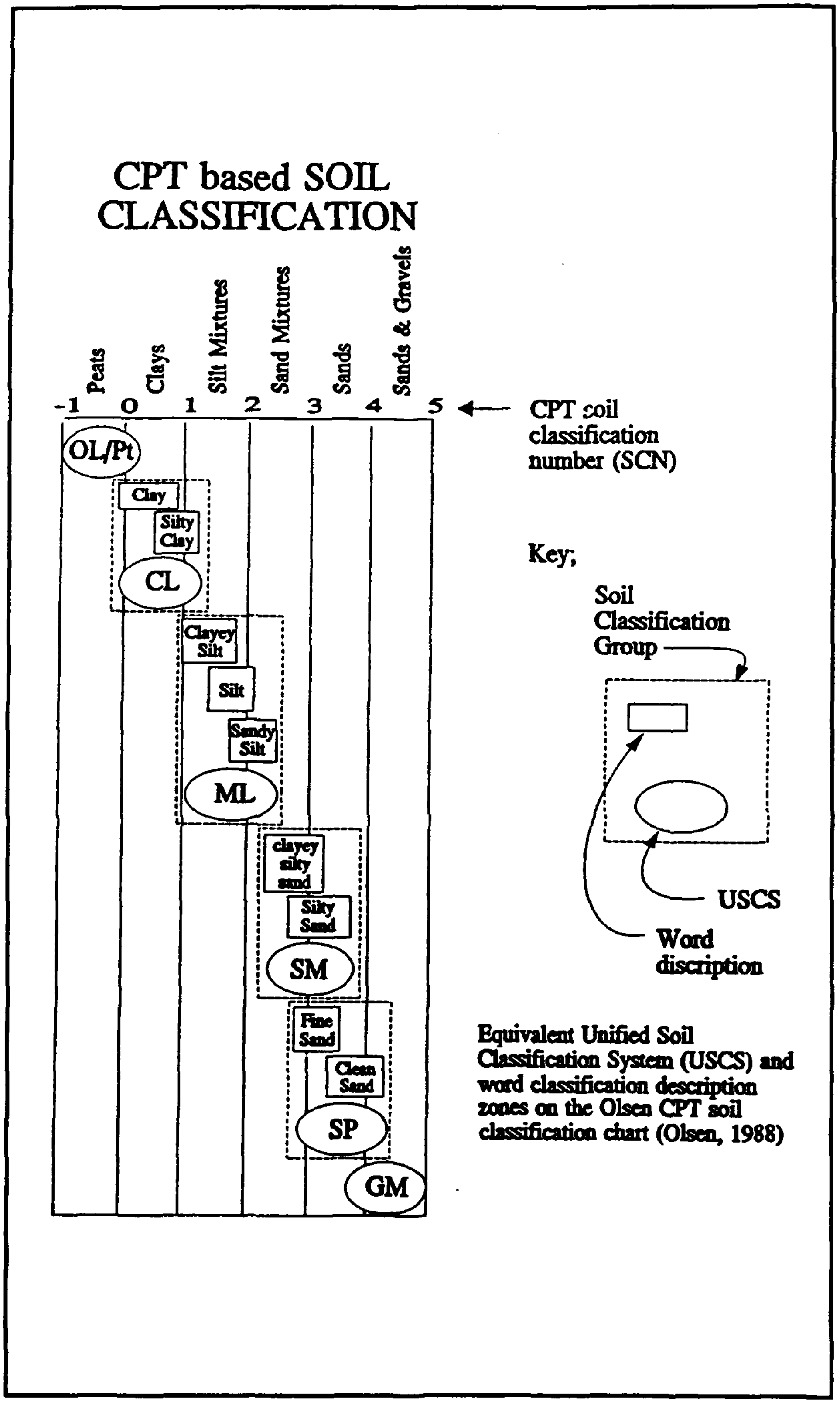


Figure 9. Graphical representation comparing Soil Classification Number (SCN) to the Unified Soil Classification System (USCS), from Olsen (1988)

Comparison to a standard reference was achieved by submerging a calibrated, temperature compensated fluid conductivity probe (Cole-Parmer Instrument Company Model No. 1481-50) to the depth of the probe electrode array. Small quantities of non-iodized table salt were added to gradually increase the conductivity of the water. Conductivity of the distilled or saline water is measured for each salt level with the fluid conductivity probe. The calibration curve so generated for the DC resistivity sensor (module) is shown in Figure 10. The resistivity compensation factor subsequently is encoded into the data acquisition software.

Soil Fluorometry Module

The laser-induced fluorometer sensor integrated with the cone penetrometer was not utilized during this project. A list of applicable literature references fully describing the WES-developed and patented system is included in the List of References.

Data Acquisition System

The data acquisition system and the post processing system each have a separate control computer (486-based personal computers). The two computers are linked by a network so that data can be exchanged during and after the penetration testing. The data acquisition computer controls all systems and stores the data on a hard disk during the penetration test. The data acquisition is directly interfaced with the amplifier/filter components for the measurement of strain on the cone tip and sleeve, amplifiers for the electrical resistivity measurements, a variable string potentiometer (which is used to calculate the depth of the penetrometer tip), a ram force indicator (which is used to determine the total force exerted on the hydraulic rams), and the computer network.

No three-dimensional visualizations of the data were presented for this project. The WES SCAPS has the ability to present three-dimensional visualization of post-processed data; the reader is again referred to the List of References for information sources. For the purposes of this report, only the truck-processed (real and near-real time) data are presented in the Results and Discussion Section.

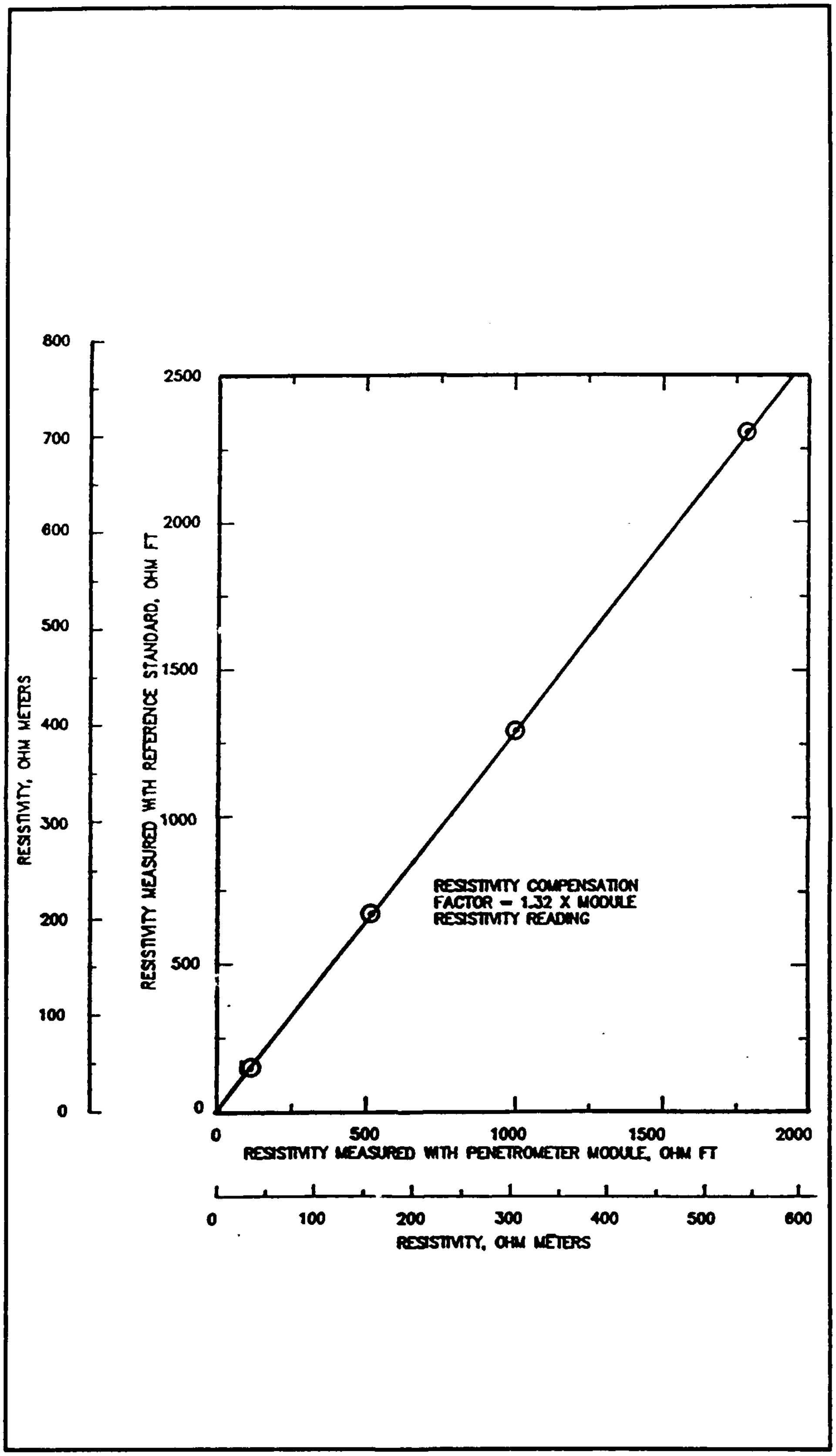


Figure 10. Resistivity calibration curve

4 Results and Discussion

General

The SCAPS cone penetrometer performed soil stratigraphy data collection at nine separate sites located within the Walnut Creek watershed (Figure 11). The sites were selected by representatives from the EPA, NSTL, and Iowa State University. The sites were spatially separated over a broad area with the intention of collecting unique subsurface data at each location. Since there were no sites where the data was grouped for gridding purposes (i.e. no push point "clusters)," four of the penetrations (at Sites 2, 3, 6, and 7) were located adjacent to previously established soil borings which had been logged by the U.S. Geological Survey (USGS) or the U.S. Environmental Protection Agency (EPA). Correlation between the boring logs and the penetrometer data logs provided a means of data quality assurance and verification of results for subsequent penetrations. Penetrometer operations in this part of the Midwest provided a challenge for SCAPS; the presence of damaging gravels, cobbles, and boulders in the subsurface geology was anticipated but their extents at the investigation sites were unknown. At the time of the site investigation, the ground surface was covered with several inches of snow and was frozen solid several inches deep.

Three of the penetration sites (Sites 1, 2, and 3) were located in the broad alluvial plain of the lower reaches of Walnut Creek. These sites are described below as the "Alluvium Sites," and the remaining six sites were located in the Upper Till zones of the watershed (described hereinafter as the "Upper Till Sites)."

Alluvium Sites

Site 1

Site 1 was located in a roadside park adjacent to the South Skunk River (Township 82 North, Range 23 West, Section 05, Southeast 1/4). The penetration was located in the middle of the park access road, approximately 50 ft

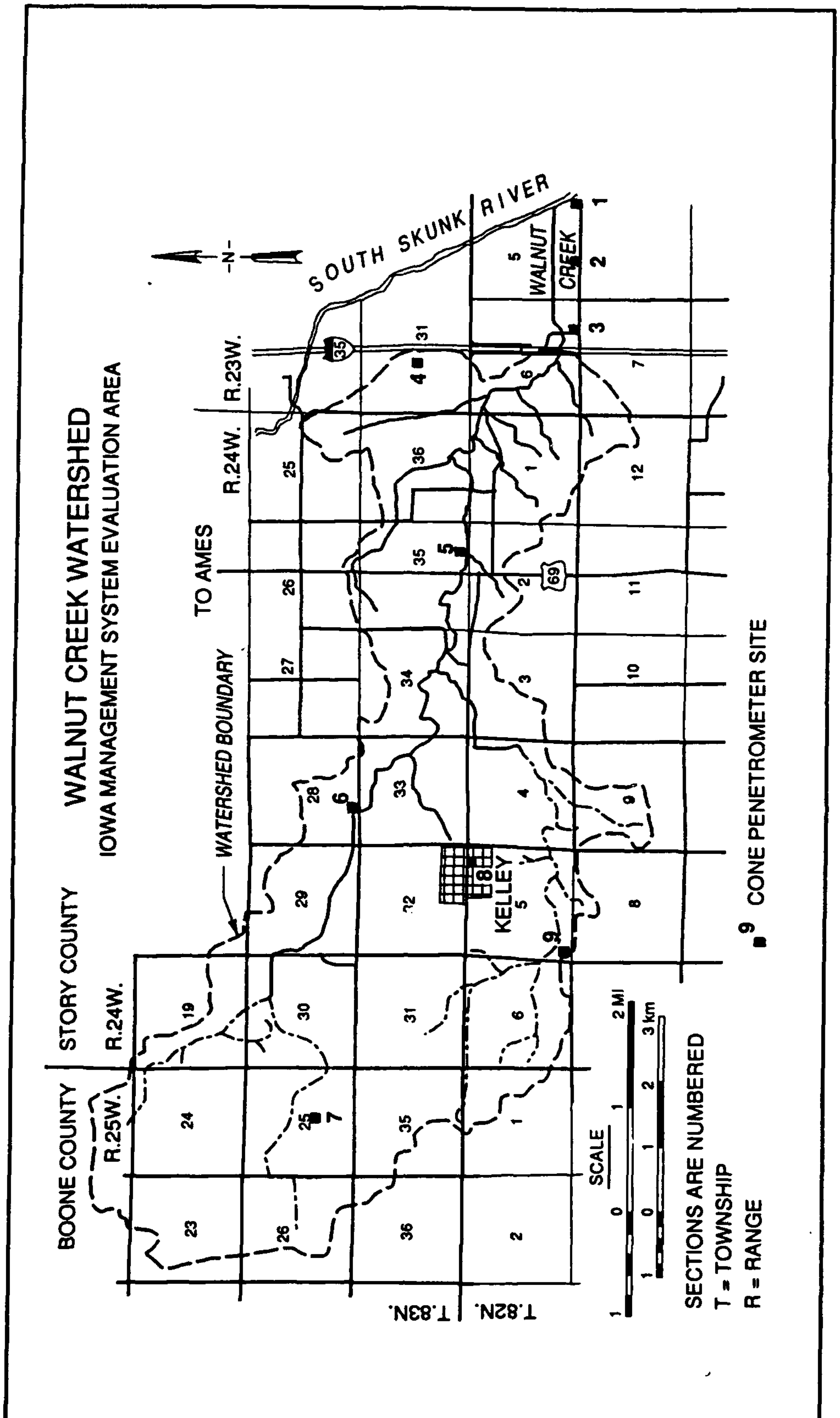


Figure 11. Penetrometer push point locations

northeast of the gravel section-line road. The park access road had a thin gravel surface, and was approximately 10 ft higher than the river surface elevation.

The SCAPS truck was positioned on site, the cone and sleeve stress response calibrations were completed (as previously discussed), and the penetrometer was advanced to 73 ft below ground surface. The hydraulic ram reached refusal at that depth; further penetration was not attempted. Refusal occurs as the hydraulic ram force approaches its safety limit (35,000 lb force). Attempting further penetration past the refusal point would have caused undue equipment stress.

The penetrometer data for Site 1 (Figure 12) indicates soil stratigraphy typical of an alluvial depositional environment. Thick deposits of coarse sands and gravels are present below the finer-grained surficial materials. Interspersed between the coarse-grained materials are relatively thin layers of finer sands and silts. The electrical resistivity sensor output also indicated interbedded deposits; the resistivity response amplitude changed as the soil classification changed. The penetrometer reached maximum ram force in a sand/gravel layer 73 ft below surface, and no evidence of weathered bedrock was observed.

Site 2

Site 2 was located in a field approximately 1/2 mile west of Site 1 (Township 82 North, Range 23 West, Section 05, Southwest 1/4). The penetration was located approximately 30 ft north of the fence line, adjacent to an old windmill. The penetration was sited within approximately five feet from an existing EPA soil boring and approximately 30 ft from an existing USGS well. The penetrometer was advanced to 89 ft below ground surface; hydraulic ram refusal was reached at that point, in a gravel layer.

The penetrometer data for Site 2 (Figure 13) indicates the presence of a distinctive finer-grained surface layer approximately 10 ft thick. Below this layer the coarser-grained material was observed as similar to Site 1. At a depth of 65 ft below surface, a well-defined clay layer with a low electrical resistivity reading was observed. The initially large resistivity response (equivalent to an open circuit) was due to a data point collected during which the soil did not contact both electrodes.

Comparisons with the 30-ft-depth USGS well boring log and the 15-ft-depth EPA coring are shown in Figure 14. The USGS well log descriptions are generalized; the detailed description is located in the Appendix. The EPA core is in the process of being finalized; the description in Figure 14 had not been typed at the time of this report. The penetrometer data is superimposed with the Unified Soil Classification System (USCS) for comparison purposes.

There are differences in soil classifications between the three data sets shown in Figure 14. The EPA data and the penetrometer data do not match

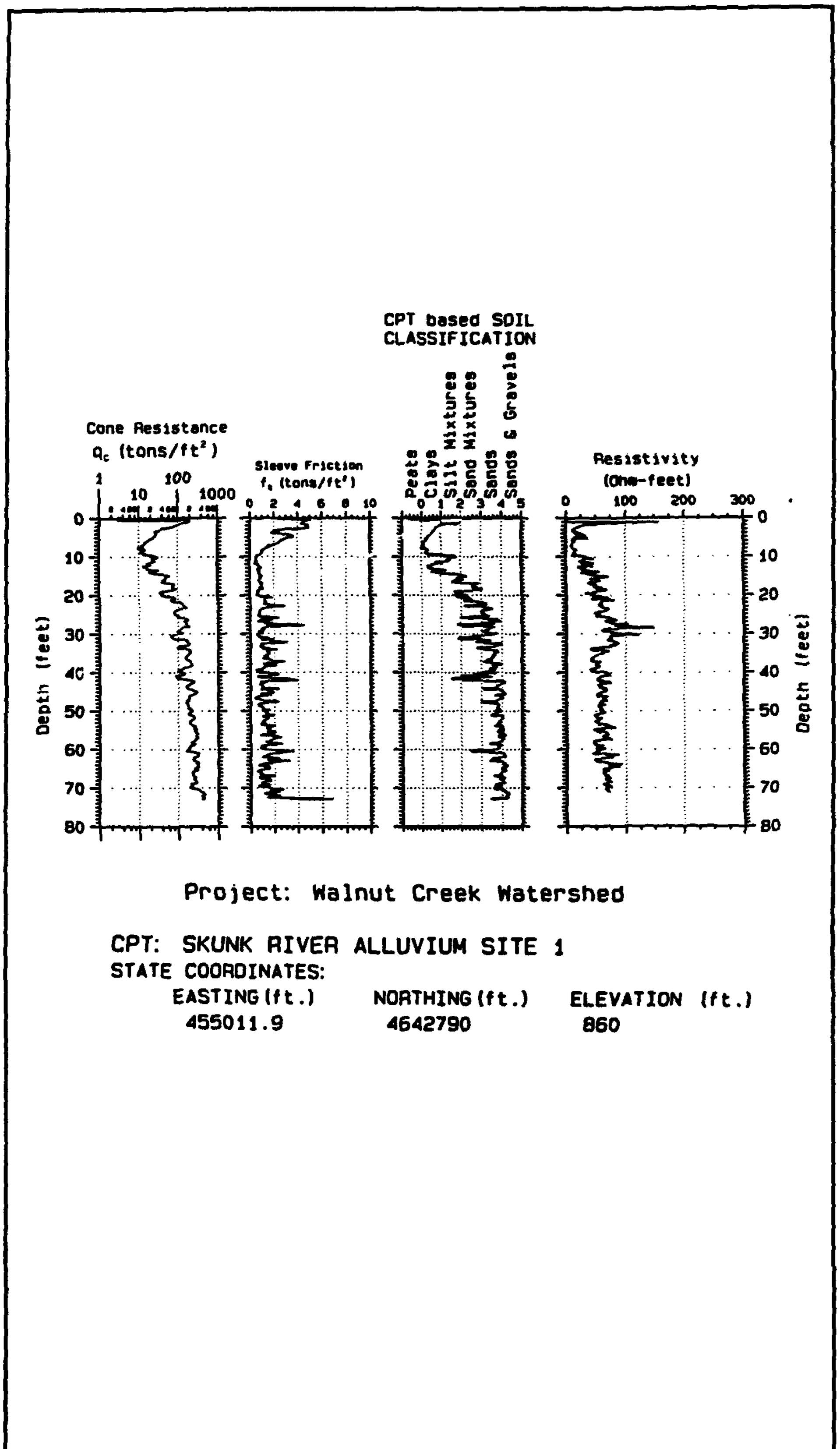
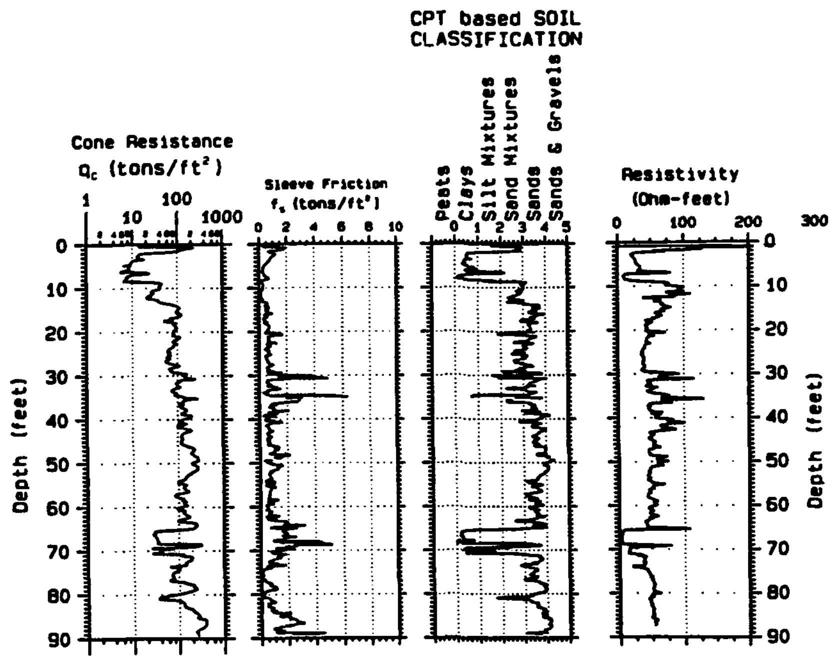


Figure 12. Penetrometer data for Site 1



Project: Walnut Creek Watershed

CPT: SKUNK RIVER ALLUVIUM SITE 2
STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
453798.3	4642849	860

Figure 13. Penetrometer data for Site 2

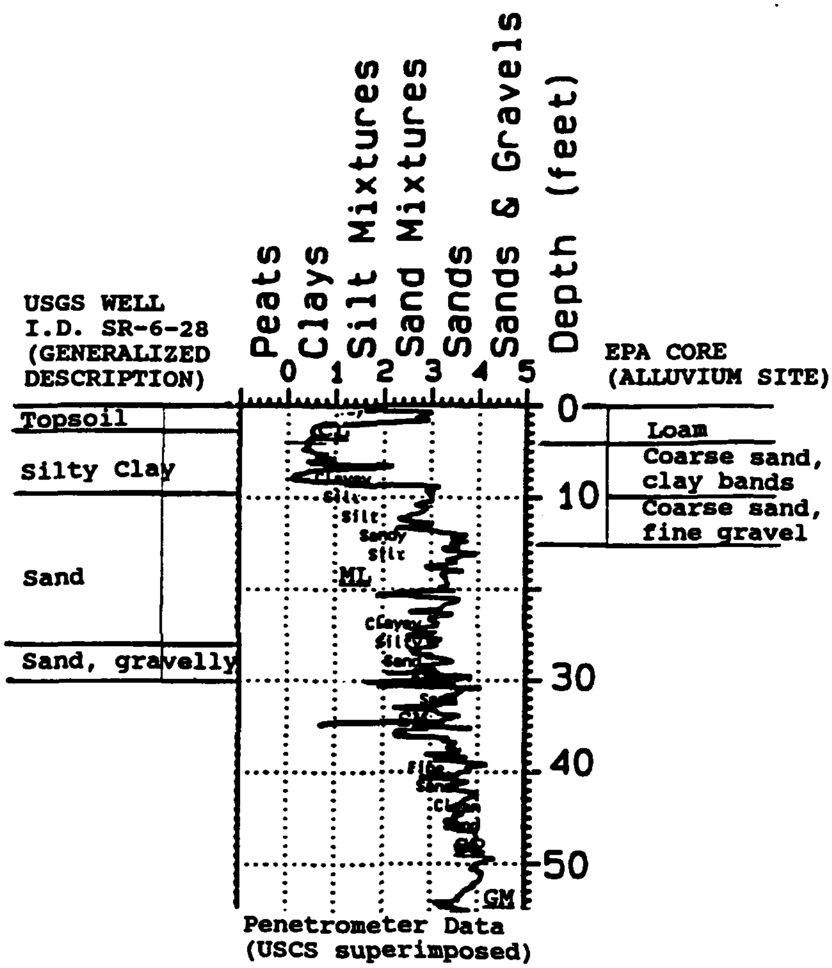


Figure 14. Comparison of penetrometer data and boring logs, Site 2

well except in the initial 4 ft of depth. Between 4 and 10 ft, the EPA data indicates predominately coarse sand, but the penetrometer data indicates predominately clay with an occasional sand lens. Between 10 and 15 ft, the EPA data indicates predominately coarse sand and fine gravel; the penetrometer indicates the coarser sands beginning at approximately 14 ft below surface. There is slight disagreement between the USGS data and the penetrometer data between 27 and 30 ft below surface. The USGS data indicates gravelly sand, and the penetrometer data indicates a finer-grained sand.

The differences in the three soil classification data sets occur in the detailed descriptions, i.e. all three sets indicate sand, but each of the three descriptions vary with respect to the sand gradation. The USGS log indicates a saturated sand, the EPA log indicates coarse sand with gravel, and the penetrometer indicates a sand mixture between a depth of 10 to 17 ft below surface. The only exception to this observation occurs at depths between 4 and 9 ft; the USGS log indicates silty clay, the penetrometer log indicates clay and sand, and the EPA log indicates coarse sand. The reason for the major soil classification difference in this 5-ft interval is unknown.

The initial two feet of penetrometer data indicates a sandy material; this is due to the increased cone tip resistance and decreased sleeve friction as the penetrometer advanced through frozen soil. The soil was a topsoil (CL material) instead of sand. This classification anomaly was encountered during each penetration event of this project.

Site 3

Site 3 was located in a field approximately one mile west of Site 2 (Township 82 North, Range 23 West, Section 6, Southeast 1/4). The penetration was located approximately 30 ft north of the fence line and a pre-existing USGS well cluster. The penetrometer was advanced to 52 ft below ground surface, and the push was terminated in a sand/gravel lense. The resistivity sensor was not utilized during this and subsequent penetrations due to a wiring malfunction within the probe. The malfunction was observed prior to the penetration during the pre-push checkout and set-up procedures, and field repair was not attempted due to its complexity.

The data for this push (Figure 15) indicates the presence of a fairly uniform clay layer extending from the surface down to a 10-ft depth. Below this layer is a thin (2-ft thick) sand lens over another thin clay lens. The soil below a 12 ft depth consists mainly of coarser textures (sands) interbedded with thin silt and clay lenses.

Comparison with the 30-ft-depth USGS log (Figure 16) indicates fairly good correlation with the cone penetrometer data. There are more variations in soil stratigraphy indicated in the penetrometer log than in the USGS log, especially in the zone between the 10 ft to 20 ft depth.

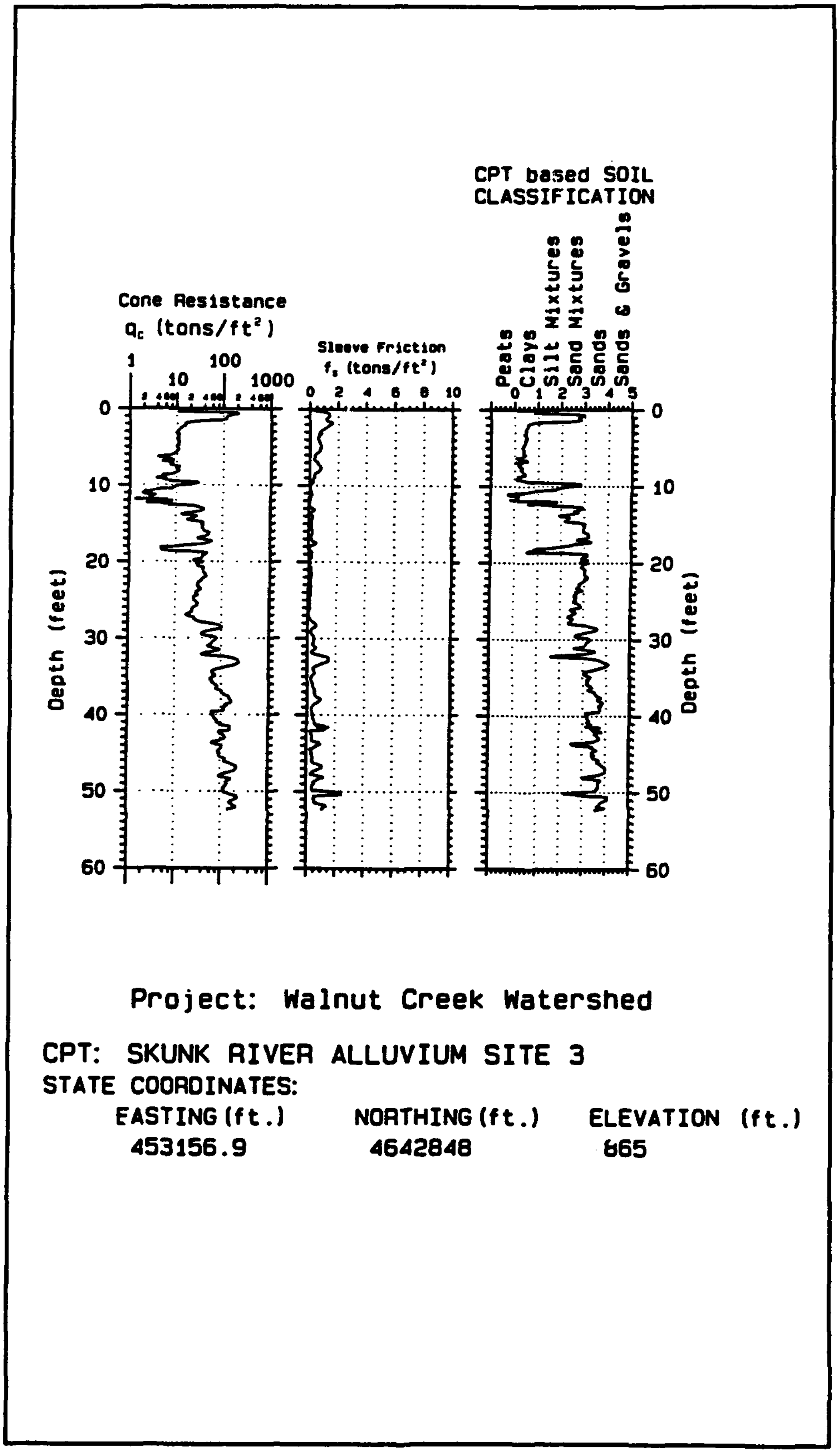


Figure 15. Penetrometer data for Site 3

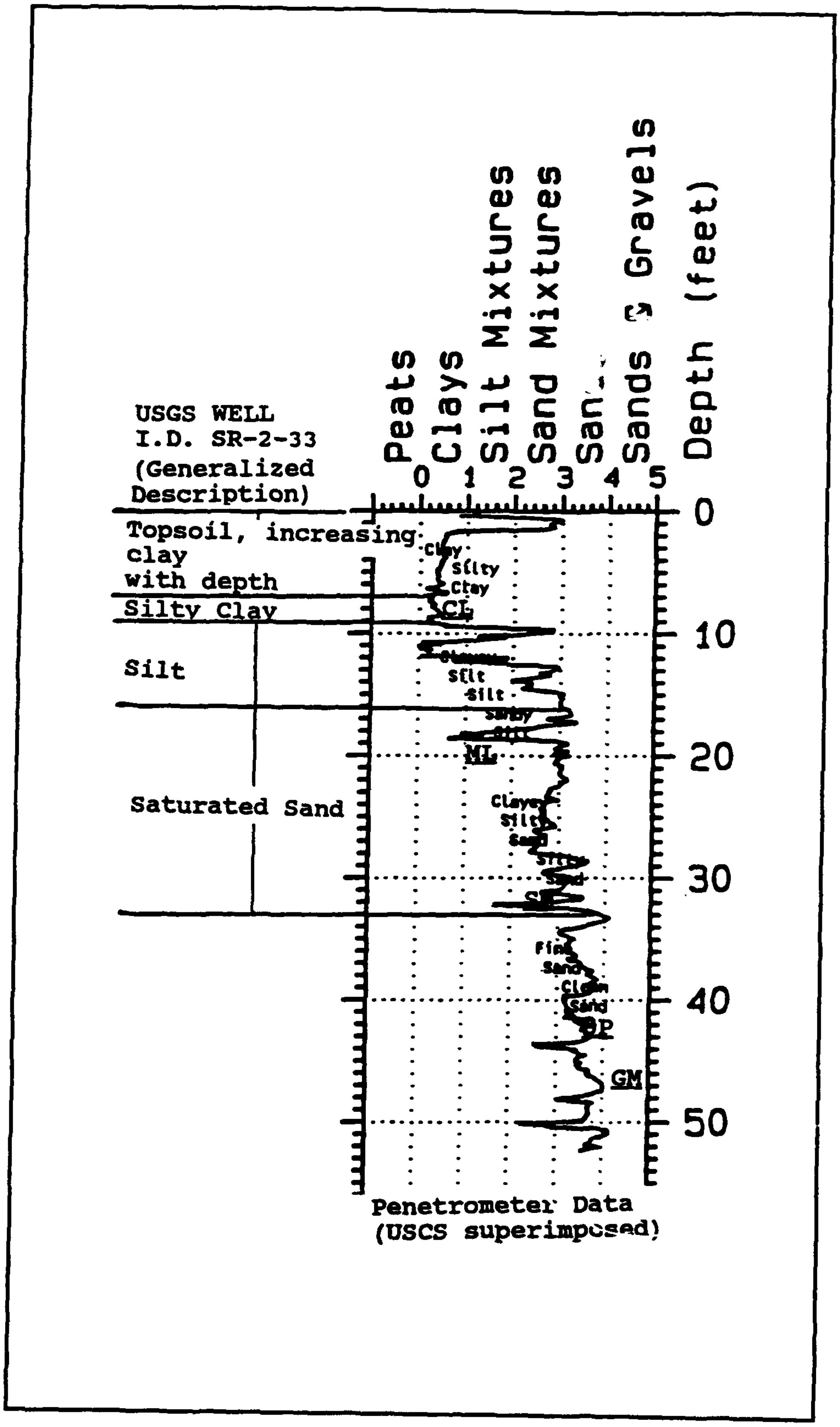


Figure 16. Comparison of data from the penetrometer and boring logs, Site 3

Upper Till Sites

Site 4

Site 4 was located in a field adjacent to (and approximately 30 ft higher elevation than) Interstate 35 (Township 83 North, Range 23 West, Section 31, Southwest 1/4). The penetration was located adjacent to the Interstate Right-of-Way fence, approximately 100 ft south of the treeline. This site is known as the "road cut," and is approximately 60 ft higher in elevation than the Alluvium Sites. The penetrometer was advanced to 52 ft below ground surface and terminated in a silt lens after audible observations indicated the presence of rock fragments that could possibly damage the probe.

Data from this push (Figure 17) indicates the presence of finer-grained soil layers than those observed in the Alluvium Sites. Silty soil predominated between the depths of 5 and 26 ft below surface; below the silt lies a fairly uniform clay layer. The spikes (pulses that extend out to the sand SCN) observed in the clay layer are due to random large rock fragments. These fragments were not large enough to prevent further penetration; their random presence indicated that these fragments were not gravel lenses as observed at the Alluvium Sites, but rather are randomly-occurring cobbles and rock fragments deposited in the till material. A demarcation between the stratified sandy silt material and a more uniform clay material is indicated at a depth of 26 ft below surface. This demarcation may be the dividing line between the diamicton above and the basal till below.

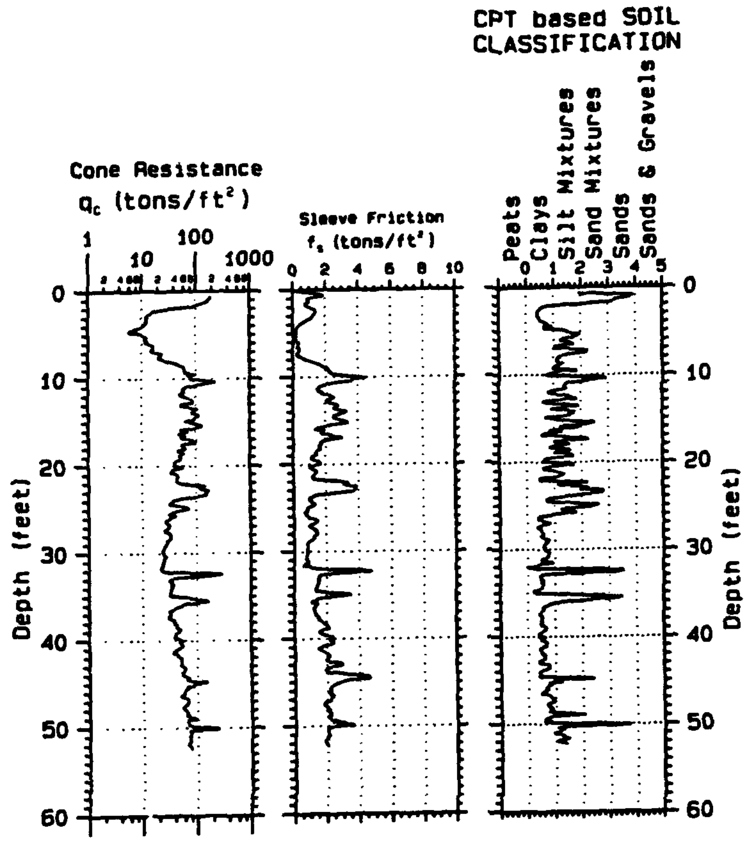
Site 5

Site 5 was located inside the Iowa State University Animal Resources Research Facility property off Highway 69 (Township 83 North, Range 35 West, Section 24, Southeast 1/4). The penetration was located across the road from the prefabricated metal buildings which are east of the sewage lagoons. This site is approximately 100 ft north of the Walnut Creek bank cut, and is approximately 35 ft higher in elevation than Site 4. The penetrometer was advanced to 50 ft below ground surface and terminated in a silt layer. Three small rock fragments (probably pebbles) were encountered during this push, at depths of 13, 28, and 40 ft.

The data (Figure 18) indicates the presence of a fairly uniform silt mixture below a 10-ft depth. A finer-grained soil layer is present between the depths of 22 and 28 ft.

Site 6

Site 6 was located north of the community of Kelley, in Township 83 North, Range 24 West, Section 28, Southwest 1/4. It is known as the "Black East" site, and is approximately 50 ft higher in elevation than Site 5.



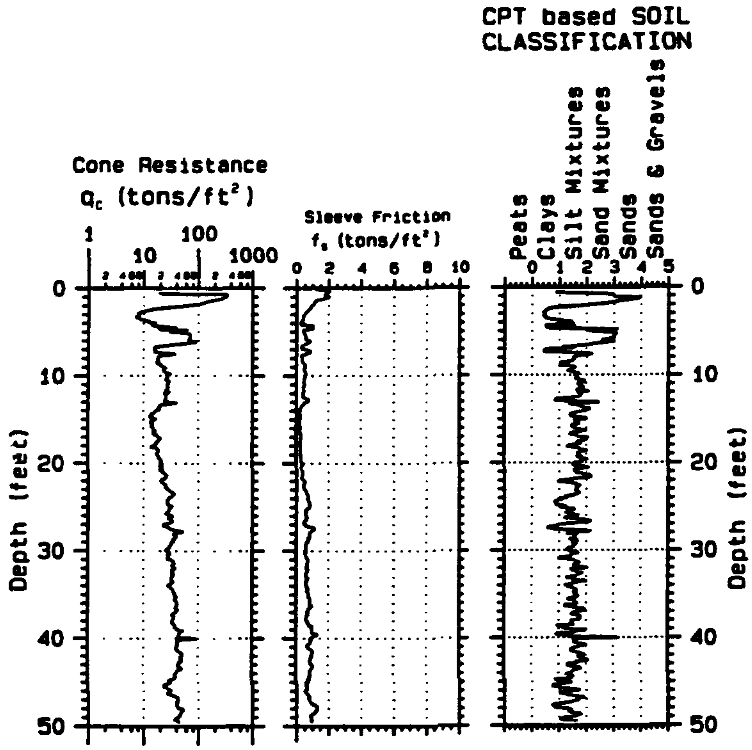
Project: Walnut Creek Watershed

CPT: UPPER TILL SITE 4

STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
452705.1	4644796	925

Figure 17. Penetrometer data from Site 4



Project: Walnut Creek Watershed

CPT: UPPER TILL SITE 5

STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
449946.2	4644697	960

Figure 18. Penetrometer data from Site 5

The penetration was located in a field approximately 100 ft off the gravel road, adjacent to a pre-existing EPA drill hole (Black East Core No. 1). The penetration was advanced to 49 ft below ground surface and terminated in a silt mixture. No rock fragments were encountered during this push. The data (Figure 19) indicates the presence of a fairly uniform silt mixture below a depth of approximately 10 ft (similar to Site 5).

Figure 20 shows the penetrometer comparison to USGS and EPA data. The soil classifications differ slightly among all three data sets. The USGS log indicates clay material, the EPA log indicates diamicton, and the penetrometer log indicates borderline silt/clay material between depths of 7 to 22 ft. The EPA log indicates (silt) loess beginning at depth 24 ft, and the penetrometer log indicates this silt material beginning at depth 21 to 22 ft. The remainder of the penetrometer log (below the 30 ft depth) indicates the silt material continues at least to a depth of 49 ft. The indication of silt material between the depths of 25 to 30 ft (seen on both the EPA and penetrometer logs) also serves to confirm the presence of the silt material as indicated on the Site 5 penetrometer log.

Site 7

Site 7 was located in the "Pothole" field (Township 83 North, Range 25 West, Section 25, Southeast 1/4). The penetration was located approximately 300 ft west of a gravel road, in a depressed area of the field. Site elevation at the penetration is approximately 30 ft higher than Site 6. The penetration was located adjacent to a pre-existing EPA drill site (Pothole Core No. P2), and approximately 100 ft from a USGS well cluster. The penetration was advanced to 50 ft below ground surface and then retracted after observing audible and visual indications (on-screen data) of rock fragments.

Data from the top 20 ft (Figure 21) indicates similarity to the push at Site 6. Below 20 ft, a remarkably uniform clay layer was observed for the duration of the penetration. Figure 22 is a comparison with USGS and EPA data; here again, the three logs differ slightly. The USGS log indicates sandy clay, the EPA log indicates diamicton, and the penetrometer log indicates a silt-to-clay material below the topsoil layer. The EPA log and the penetrometer log appear to disagree regarding demarcation zones between the silt (loess) and clay materials. The EPA log indicates the clay zone begins at a depth of 23 ft; the penetrometer log indicates the clay zone beginning at a depth of 21 ft. The probable explanation of the depth difference between the two logs is that the ground surface, in addition to being covered with snow, was deeply furrowed by plows. The 2-ft difference could have been caused by such height variations at the ground surface.

Site 8

Site 8 was located in the community of Kelley (Township 82 North, Range 24 West, Section 05, Northeast 1/4). The penetration was located in a field

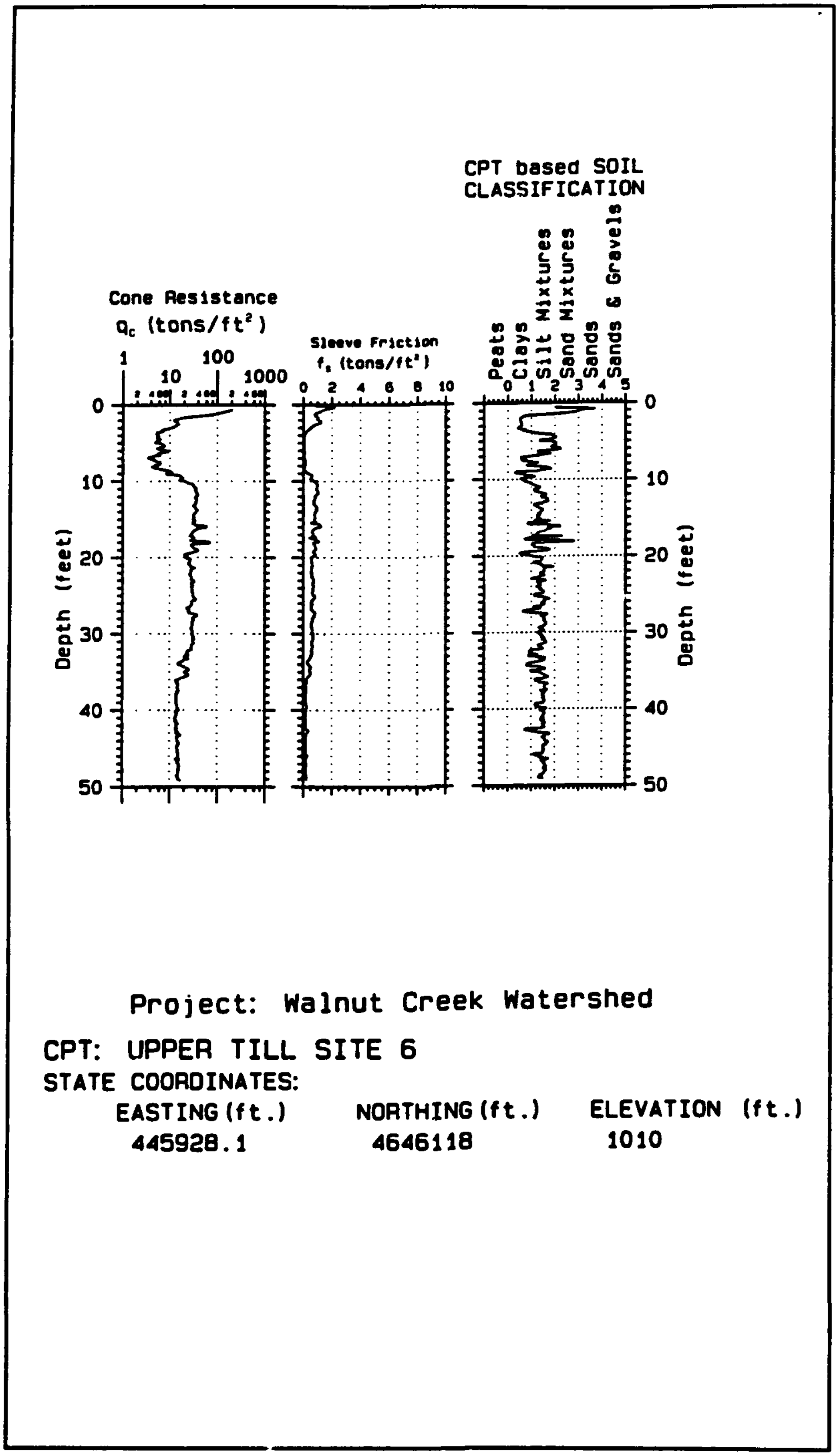


Figure 19. Penetrometer data from Site 6

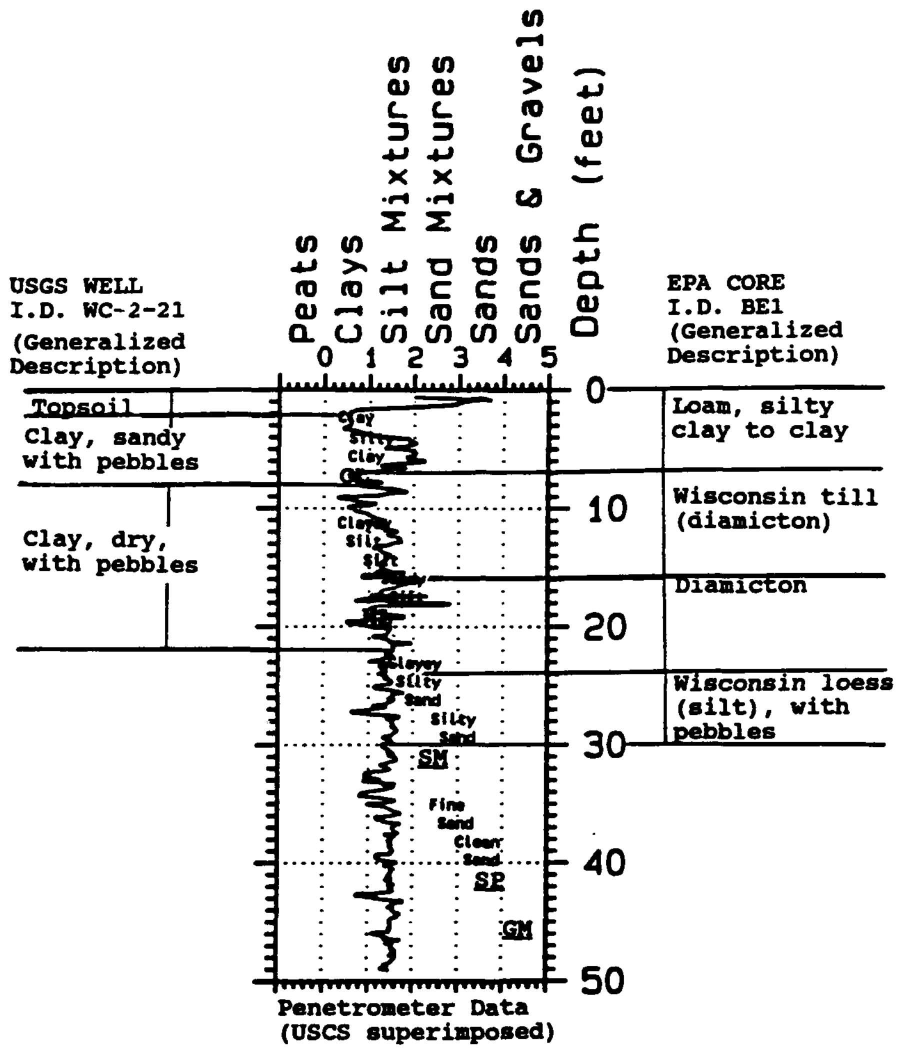
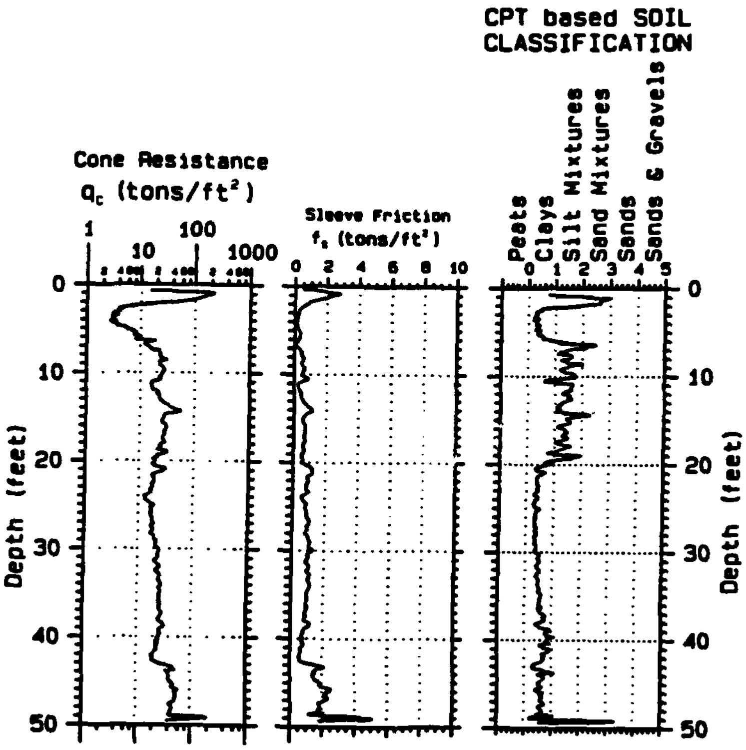


Figure 20. Comparison of penetrometer data and boring logs, Site 6



Project: Walnut Creek Watershed

CPT: UPPER TILL SITE 7

STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
441988.7	4646366	1040

Figure 21. Penetrometer data from Site 7

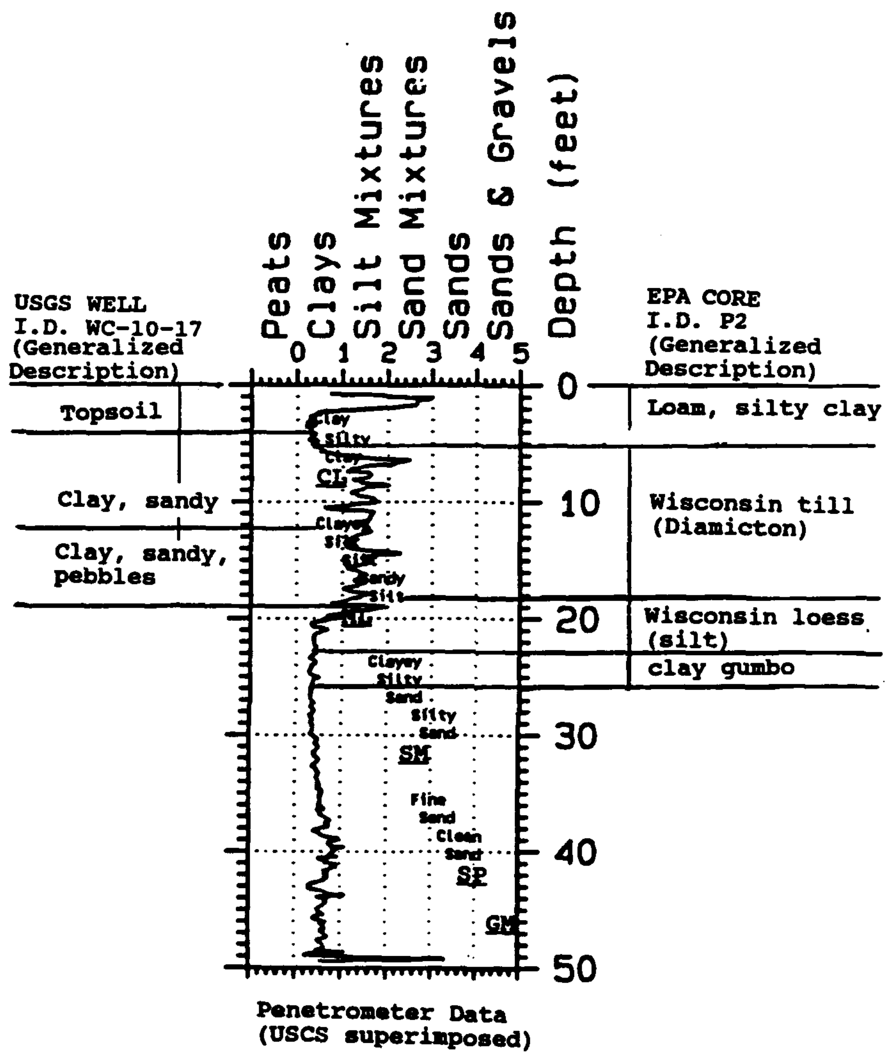


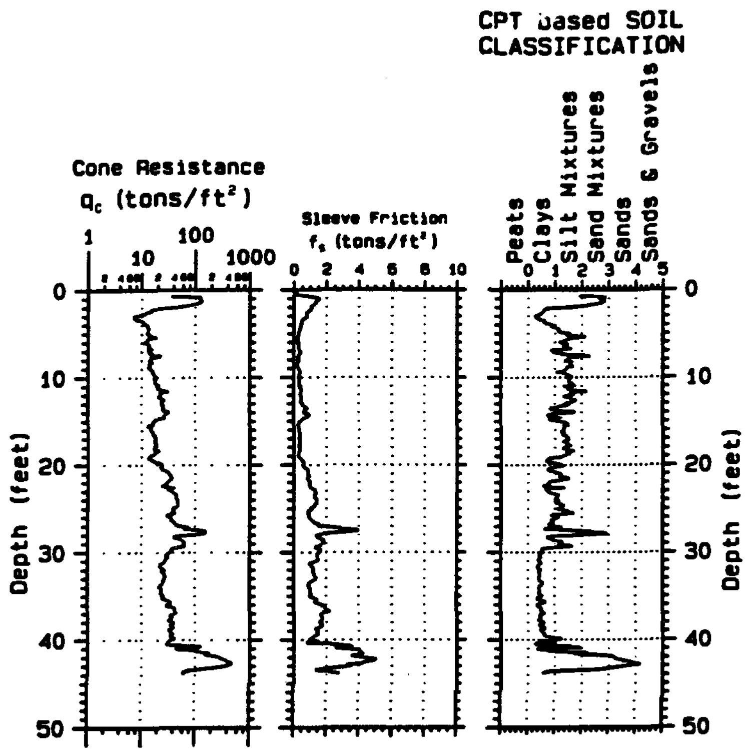
Figure 22. Comparison of penetrometer data and boring logs, Site 7

adjacent to a Kent™ grain silo complex, approximately 75 ft south of the paved highway. The site elevation is approximately 10 ft higher than Site 7. The penetration was advanced to 45 ft below ground surface. Hydraulic ram refusal was reached at that depth; rock fragments were the most likely cause. Further penetration was not pursued due to the likelihood of equipment breakage.

The data (Figure 23) suggests the presence of a silt layer approximately 30 ft thick. A uniform clay layer was observed below the silt layer, and is at approximately the same elevation as the top of the uniform clay layer observed at Site 7 (1000 ft above MSL). Based on the EPA log at Site 6, the material between the depths of 6 ft and 30 ft may generally be classified as diamicton till. The material below 30 ft is inferred to be composed of basal till, due to its textural uniformity.

Site 9

Site 9 was located southwest of the community of Kelley (Township 82 North, Range 24 West, Section 05, Southwest 1/4), at the edge of the Walnut Creek watershed boundary. The penetration was located in a field approximately 50 ft north of a single family house. The penetration was advanced to 23 ft below ground surface. At that point, the output voltages sharply indicated a cone tip strain gage anomaly; it was immediately determined that the tool had been broken by a subsurface obstruction, and the push was terminated. An impenetrable rock most likely caused sideward deflection of the push pipe, exponentially increasing the bending stress and thus overstressing a threaded pipe connection. Data obtained above the termination depth (Figure 24) indicates a surface cap of clay (8 ft thick) underlain by silt and diamicton layers.



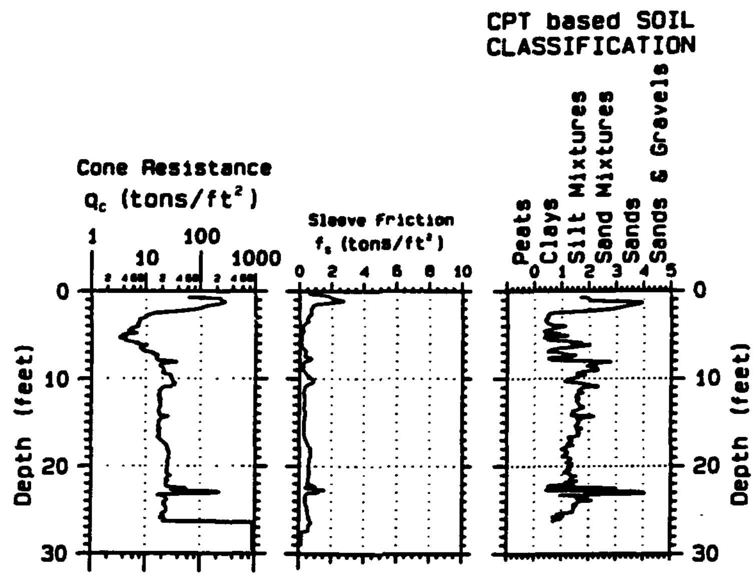
Project: Walnut Creek Watershed

CPT: UPPER TILL SITE 8

STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
445024	4644447	1030

Figure 23. Penetrometer data from Site 8



Project: Walnut Creek Watershed

CPT: UPPER TILL SITE 9

STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
443747.1	4642919	1030

Figure 24. Penetrometer data from Site 9

5 Conclusions and Recommendations

Conclusions

The Soil Classification Number (SCN) on each of the data plots indicating sandy material in the top two feet is not accurate; the frozen clay surface caused the cone resistance and sleeve friction strain gages to respond to the higher stresses as the probe was pushed through the surface, thus registering a higher SCN value. The presence of subsurface rock fragments may also mask the actual soil classification by exhibiting "spikes" in the data. Such interferences are readily apparent during the penetration event.

The data from the Alluvium Sites exhibit a consistent trend; a clay surface cap up to 10 ft thick overlies interbedded coarser-grained deposits. These deposits are not uniform in thickness or texture, and extend to depths at least 89 ft below surface (approximate elevation 771 ft MSL).

The data from the Upper Till Sites indicate the finer-grained nature of the soil material. The cone penetrometer logs allow rapid distinction between the diamicton till and the finer-grained uniform basal till zones at Sites 4, 7, and 8. The approximate elevations of the top of the more uniform clay deposit are 900, 1020, and 1000 ft MSL, respectively. The distinction between diamicton till and the Wisconsin loess is not as readily apparent; correlation with borehole logs is required to accurately distinguish between the two materials.

The correlation between the penetrometer data and the adjacent borehole logs was evident. The penetrometer-inferred soil classifications compared fairly well in three out of four cases. The data from Site 2 did not compare as well, due to unknown reason. Since disagreement was observed between all three logs (USEPA, USGS, and the SCAPS), it is apparent that no one log is suspect. Minor differences in elevations were due to the condition of the ground surface (snow cover and furrow depths); a pre-push hole approximately 6 in. deep was manually chopped through the ice to prevent the penetrometer tip from sliding off axis as it entered the ground surface. The penetrometer was advanced to deeper depths than the existing adjacent boreholes, but data from the boreholes may be utilized to interpret and provide a means of verification of the deeper penetrometer data.

Recommendations

The SCAPS system was operated in the coldest weather ever encountered during a SCAPS project. The primary reasons for operating during the winter were to prevent tire rut damage to the fields and to avoid the crop growing season conflicts with the local farmers. Temperatures to -20° F prevented the usage of the retraction grouting and steam cleaning systems. Special considerations for truck operation and crew safety were required. The truck engine and hydraulic pumps were required to be operated around the clock to prevent freeze-ups or cold-stressing of moving mechanisms. Prevention of frostbite was a primary concern for personnel when outside of the heated truck environment. It is recommended that no future projects be conducted during such severe winter conditions.

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Appendix A

Soil Boring Logs

USGS and USEPA

SITE 2

USGS
Well Identification: SR-6-28
County: Story

Date: 4/15/92
Location: T82NR23W Sec 05 SW1/4

Depth Interval	Description
0 - 2.0	Topsoil
2.0 - 6.0	Silty clay, dark brown, cohesive
6.0 - 7.0	Silty clay, medium brown, cohesive
7.0 - 8.0	Silty clay, medium brown, sandy, cohesive
8.0 - 9.0	Same as above, lighter brown
9.0 - 17.0	No cuttings, saturated sand
17.0 - 23.0	Sand, brown, fine, watery
23.0 - 27.0	Sand, courser, color changing to gray
27.0 - 29.5	Sand, gravelly, hard drilling
	Could not drill deeper due to gravel

EPA CORE ALLUVIUM SITE
(Descriptions from Iowa State University pre-draft boring log)

0 - 45 inches	Loamy alluvium, black to dark gray
45 - 121 inches	Coarse sand with occasional clay banding
121 - 184 inches	Coarse sand and fine gravel, mixed

End of Borehole

SITE 3

USGS

Well Identification: SR-2-33 | Date: 4/10/92
County: Story | Location: T82NR23W Sec 06 SE1/4

Depth Interval	Description
0 - 4.0	Topsoil, black, increasing clay with depth
4.0 - 7.0	same as above but becoming browner with depth
7.0 - 9.0	Silty clay, becoming lighter brown
9.0 - 11.0	Silt, tan
11.0 - 16.0	Silt, tan, soft
16.0 - 33.0	No cuttings, saturated sand

SITE 6

USGS

Well Identification: WC-2-21 | Date: 2/26/91
County: Story | Location: T83NR24W Sec 28 SW1/4

Depth Interval	Description
0 - 0.5	Topsoil, black, organic, frozen
0.5 - 2.0	Topsoil, black, organic
2.0 - 5.5	Soil, medium brown, clayey, cohesive
5.5 - 6.0	Clay, mottled brown-gray, very sandy, pebbles
6.0 - 8.0	Clay, bluish-gray, wet
8.0 - 9.0	Clay, blue-gray, pebbles, appears dry, very stiff
9.0 - 18.0	Clay, blue-gray grading to dark gray with depth, pebbles, stiff, cohesive
18.0 - 22.0	Clay, dark gray, stiff cohesive

SITE 6

Black East Core #1 (BE1)

Cored on February 2, 1993, using a CME-55 EPA Rig equipped with a CME 4 inch continuous core sampler. The full 4 inch core was described. Core described by Bill Simpkins and Michael Thompson (Iowa State University). Soil is a fine, loamy cumulic Hapludoll.

Depth (ft)	Description
0.0 to 1.3	Silty clay loam, N 2/0, moderate fine to medium subangular blocky, few very fine roots, non-calcareous, few thin 1 mm sand stringers
1.3 to 2.1	Silty clay loam, 10 YR 2/1, weak medium subangular blocky, increase in coarse fragments to 5%, slightly more sand than above, one sand stringer noted.
2.1 to 2.9	Clay loam, 10 YR 2/1, weak moderate subangular blocky, fine sand stringers 2 mm thick at 2.3 to 2.5 ft, non-calcareous, gradual boundary.
2.9 to 5.8	Loam, 10 YR 3/1, massive, few medium faint mottles (10 YR 4/1), sandy zones, non-calcareous
5.8 to 6.9 missing (sand?)	
6.9 to 8.5	diamicton (till-derived colluvium), 5Y 6/2 matrix with vertical 2.5Y 3/0 infillings (Krotovinas?), calcareous
8.5 to 10.3	diamicton (probably late Wisconsin till), weathered?, 5Y 6/2, Fe stained fracture surfaces (10YR 6/8) on horizontal and vertical surfaces, oxidation is variable, roots and organic material throughout, limestone pebble, calcareous
10.3 to 15.3	diamicton (late Wisconsin till), unweathered, 5Y 4/1, greenish cast, lots of limestone pebbles, calcareous, fractures not apparent here
15.3 to 15.5	diamicton (late Wisconsin till), transition zone of 5Y 5/2 next to sand lens below
15.5 to 15.6	sand, unoxidized, pepper sand, lost some core, lots of water
15.6 to 15.83	diamicton (late Wisconsin till), transition zone of 5Y 5/2 next to sand lens above
15.83 to 16.8	diamicton (late Wisconsin till), unweathered, 5Y 4/1, calcareous
16.8 to 22.75	diamicton (unknown till), unweathered, clayier than above, variegated appearance, greenish blue cast of 5G 3/1 or 5Y 5/2 with Fe streaks of 2.5Y 6/6 running vertically, dark organic spots, very calcareous, silt parting at bottom of core; this appears an incorporated block of Tazewell till or Pre-Illinoian till..
22.75 to 23.8	diamicton (late Wisconsin till), unweathered, 2.5Y 4/0, very calcareous, no fractures apparent, looks identical to that in the 15.83 to 16.8 ft interval.
23.83 to 28.0	silt (Wisconsin loess), 5GY 4/1, 1 mm size gastropod shells, dark organic splotches and banding, good H_2S smell.
28.0 to 30.0	silt (Wisconsin loess), 5GY 4/1, some Fe staining, some limestone pebbles in here!

Bottom of borehole @ 30 ft

Pothole Core #2 (P2)

Cored on January 31, 1993, using a CME-55 EPA Rig equipped with a CME 4 inch continuous core sampler. The full 4 inch core was described. Core described by Bill Simpkins and Michael Thompson (Iowa State University). Soil appears to be a Cumulic Hapludoll (Okoboji).

Depth (ft)	Description
0.0 to 0.5	Mucky silt loam, N 2/0, moderate, fine, medium subangular blocky, common fine roots, non-calcareous
0.5 to 1.0	Mucky silt loam, N 2/0, strong, fine, medium, subangular blocky, few fine roots, non calcareous
1.0 to 1.25	Mucky silt loam, N 2/0, moderate, fine, medium subangular blocky, few very fine roots
1.25 to 1.9	Silty clay loam, 10 YR 2/1, weak, fine to moderate subangular blocky, few roots, few fine 1-2 mm biopores, one possible mottle, 3 to 5% coarse fragments, non-calcareous
1.9 to 2.2	Silty clay loam, 10 YR 2/1, streaks and pockets of bioturbation (2.5 Y 6/2), few medium distinct mottles (2.5 Y 5/4), non-calcareous
2.2 to 3.8 missing (sand?)	
3.8 to 4.0	Light silty clay loam, massive, 2.5 Y 6/2, common medium faint mottles (2.5 Y 6/6), weakly calcareous
4.0 to 5.2	Light silty clay loam, 5Y 6/1, very wet, calcareous, common high chroma mottles (2.5Y 6/6), sticky, heterogeneous and sandy in spots
5.2 to 7.1 missing (more sand?)	
7.1 to 9.0	diamicton (late Wisconsin till), sandy, 2.5Y 4/2 (remnant oxid. zone?), calcareous, Fe is *reduced but oxidizing immediately*
9.0 to 17.7	diamicton (late Wisconsin till), unweathered, more cohesive, 2.5Y 4/0 and grayer in color, excellent oxidized Fe-oxide fracture surfaces here, calcareous, limestone pebbles at 16 ft.
17.7 to 21.7	silt (Wisconsin loess), unweathered or reduced, 2.5Y 3.0, organics abundant in blobs, very thin vertical fractures with thick coatings of organic carbon (produced in one event?), HCl releases H_2S.
21.7 to 23.0	silt (Wisconsin loess) as above, slightly clayier in this interval?
23.0 to 25.5	clay gumbo (Yarmouth-Sangamon paleosol), unweathered, 5G 5/1, gleyed colors alternate with a 10R 4/2 or 10 YR 4/2 - 4 cm wide strip interpreted as krotovinas by MLT, slightly calcareous, some wood chips, a little bluer than normal

bottom of borehole @ 25.5 ft.

SITE 7

USGS

Well Identification: WC-10-17 Date: 4/02/91
County: Boone Location: T83NR25W Sec 25 SE1/4

Depth Interval	Description
0 - 3.5	Topsoil, black, clayey, organic
3.5 - 6.0	Clay, gray olive-brown, sandy, oxidized
6.0 - 8.0	Clay, brown gray, mottled, sandy, oxidized, appears dry
8.0 - 11.0	Clay, rusty brown, no mottling, wet at 9.0, sandy
11.0 - 12.0	Clay, brown gray, mottled, sandy
12.0 - 18.5	Clay, dark gray, sandy, pebbles, cohesive

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13. ABSTRACT *(Maximum 200 words)*

Nine sites within the Walnut Creek watershed basin near Ames, Iowa, were investigated with the U.S. Army Engineer Waterways Experiment Station Site Characterization and Analysis Penetrometer System (SCAPS). The SCAPS performed soil classification and stratigraphy with the conventional cone penetrometer. Electrical resistivity measurements were made at two sites with the penetrometer-mounted resistivity sensor. Soil stratigraphy verification with adjacent soil boring logs (provided by other government agencies) was also accomplished. The penetrometer data from each of the nine sites were collected to augment the research efforts within the Walnut Creek Management System Evaluation Area, being conducted by the U.S. Department of Agriculture and the U.S. Environmental Protection Agency.

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